Aerial Haze and its Effect on Photography from the Air

Monographs on the Theory of Photography, from the Research Laboratory of the Eastman Kodak Company

No. 4

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Aerial Haze and its Effect on Photography from the Air

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Monographs on the Theory of Photography

Edited by

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Preface to the Series

The Research Laboratory of the Eastman Kodak Company was founded in 1913 to carry out research on photography and on the processes of photographic manufacture.

The scientific results obtained in the laboratory are published in various scientific and technical journals, but the work on the theory of photography is of so general a nature and occupies so large a part of the field that it has been thought wise to prepare a series of monographs, of which this volume is the fourth. In the course of the series it is hoped to cover the entire field of scientific photography, and thus to make available to the general public material which at the present time is distributed throughout a wide range of journals. Each monograph is intended to be complete in itself and to cover not only the work done in the laboratory, but also that available in the literature of the subject.

A very large portion of the material in these monographs will naturally be original work which has not been published previously, and it does not necessarily follow that all the views expressed by each author of a monograph are shared by other scientific workers in the laboratory. The monographs are written by specialists qualified for the task, and they are given a wide discretion as to the expression of their own opinions, each monograph, however, being edited also by the director of the laboratory, by Mrs. Schramm, and by Miss Garvin, who is now the active editor of the series.

Rochester, New York
August, 1923

Preface

In 1918, the Research Laboratory of the Eastman Kodak Company undertook, in collaboration with the Department of Military Aeronautics of the United States Army, a study of photography from the air with regard especially to the problems presented by aerial haze, the immediate object of the study being, of course, its application to military aerial photography.

The work in the laboratory was under the immediate direction of Mr. Kenneth Huse, who was assisted by Drs. Walter Colby and William Sleator, of the University of Michigan, who spent a year in the Research Laboratory for the purposes of this investigation. Many other members of the staff of the laboratory collaborated in the work, which was under the general direction of Dr. C. E. K. Mees, the director of the Research Laboratory.

Captain A. K. Chapman, stationed in Rochester for the Science and Research Division, collaborated in all the aerial work of the Eastman Kodak Company and especially in the arrangements necessary for the carrying out of this investigation. Captain H. E. Ives, who was in general charge of the aeroplane investigations of the Science and Research Division, also assisted greatly in the work. Thanks are also due especially to Lieutenant A. H. Nietz who, while stationed at the Langley Flying Field at Hampton, Va., did a great deal of flying in connection with the work, and placed many of his results at our disposal.

The work had not been completed when the Armistice was signed, in November, 1918. By consent of the military authorities, it was brought to a conclusion sufficient to enable general results of practical value to be deduced from the measurements, and the work was then closed, though in only a partially completed state. Nevertheless, it has been thought desirable to publish the results obtained and especially the methods employed, so that any future work along these and similar lines may have the advantage of the experience gained. We feel that in spite of the incomplete state of the work, the results obtained are of considerable value as indicating the best conditions for aerial photography, the types of materials which should be used, and the conditions under which they should be employed.

We are indebted to the Department of Military Aeronautics for its kind permission to publish the work in this monograph.

Rochester, New York
August, 1923

Aerial Haze and its Effect on Photography from the Air

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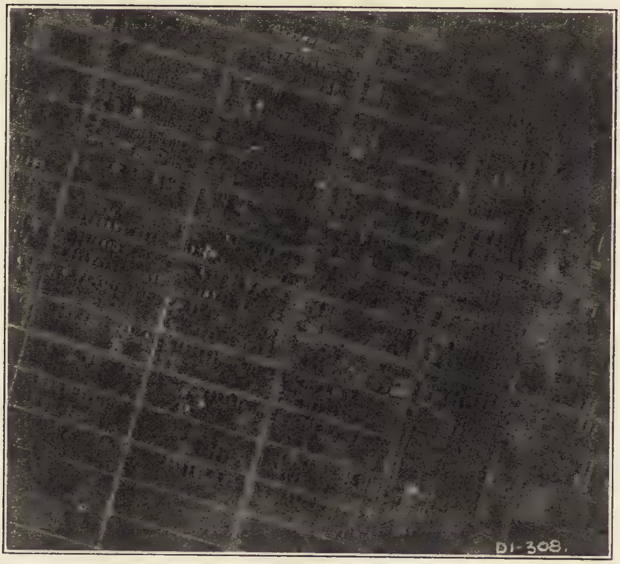

FIG. 1A

FIG. 1B
Showing elimination of haze

Aerial Haze and its Effect on Photography from the Air

CHAPTER I

Introduction

Aerial photography differs from most branches of photography in that the distance between the camera and the object photographed is very great, so that between the lens and the subject there exists a depth of air which reflects light back into the lens. This light, reflected from particles of water or dust suspended in the air and, to a less extent, from the molecules of air themselves, superimposes a uniform illumination over all parts of the subject photographed, causing a veiling haze which diminishes the contrast available for reproduction in the photograph. The term "haze," though indefinite, specifies a phenomenon with which every one is familiar. Distant landscapes in regions of ordinary humidity almost always show haze, which appears as a thin veil of bluish cast.

In photographing mountains haze frequently causes trouble, diminishing the contrast to a serious extent. In no branch of photography, however, is haze so important as in photography from the air. Owing to the large proportion of actinic light reflected in haze, its effect is much greater photographically than visually, often being serious in photographs taken under visually clear conditions. At altitudes of 10,000 feet or more, the haze effect is frequently so marked that it becomes difficult to distinguish ground detail in the photograph, while the taking of long distance obliques is almost impossible without precautions for the elimination of haze.

The following series of photographs illustrates quite forcefully the very undesirable results arising from the presence of haze in the air. Fig. 1 shows two successive photographs of the same subject taken from a height of 10,000 feet. Fig. 1A was made on an ordinary plate with no special means of dealing with haze. Fig. 1B was made on a special plate under conditions such that the haze effect was largely removed. The prints from these negatives were made without any special treatment.

Fig. 2 shows two photographs made on the same emulsion at exactly the same time by means of a camera with multiple

lenses. Fig. 2A was made in the ordinary way; Fig. 2B shows the elimination of the haze effect. It is quite surprising how

FIG. 2A
Taken on ordinary plate

much more detail, especially in the woods and fields (the dark areas), is shown by the picture less affected by haze. These photographs were taken at an altitude of 11,000 feet, and it is interesting to note that haze was not apparent to the eye, the day being considered a very good one for air work.

Fig. 3 shows a case of much denser haze, although still not of haze at its maximum. In this case the altitude was 10,500

feet. Clouds were rather uniformly distributed in a layer at about 6,500 feet. Looking downward from a height of 10,500

Fig. 2B
Taken with filter

feet, the earth was almost invisible, as the spaces between the clouds were apparently occupied by haze. These spaces appeared very blue.

There are times when haze (in the absence of any cloud formations) becomes so dense that the earth can scarcely be seen, even from low altitudes. This is more likely to occur in autumn than in spring, the haze consisting to a greater

extent of dust and smoke particles than of water vapor. Certain regions would, of course, never experience haze of this sort, and, furthermore, some districts would be on the average quite free from haze in troublesome quantities. The southwestern part of the United States is quite free from haze, and there no difficulty is experienced, as a rule, in securing clear aerial photographs by ordinary methods. It should not be understood that haze is always present in sufficient amount to annoy the photographer. From lower alti-

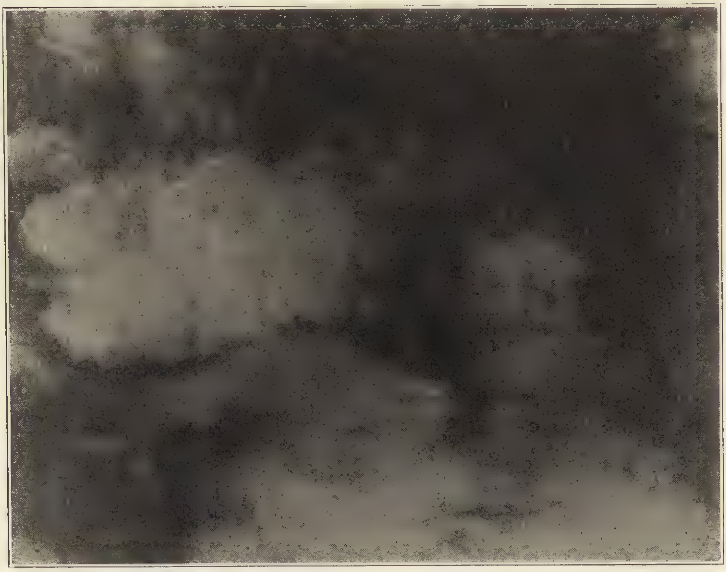

Fig. 3A

tudes little difficulty is encountered from this cause, but at high altitudes better photographs can always be secured by considering the haze effect.

There is no likelihood of our being able to photograph through extremely dense layers of haze, since radiation (of whatever wave-length) reflected from the haze body will often be greater than that reflected from the earth and transmitted by the haze. Therefore, when anyone speaks of photographing through several miles of "mist" or "fog" he is either misapplying the terms mist and fog to what we usually consider haze, or he is working on the credulity of the general

public, which has not yet become familiar with the process. It is impossible by any method known at present (such, for instance, as photography by the infra-red) to photograph through mist which is any more dense than that through which one can just distinguish the highlights of the subject to be photographed.

Our visual perception of space depends upon contrast—that is, upon differences of brightness. While it is often stated

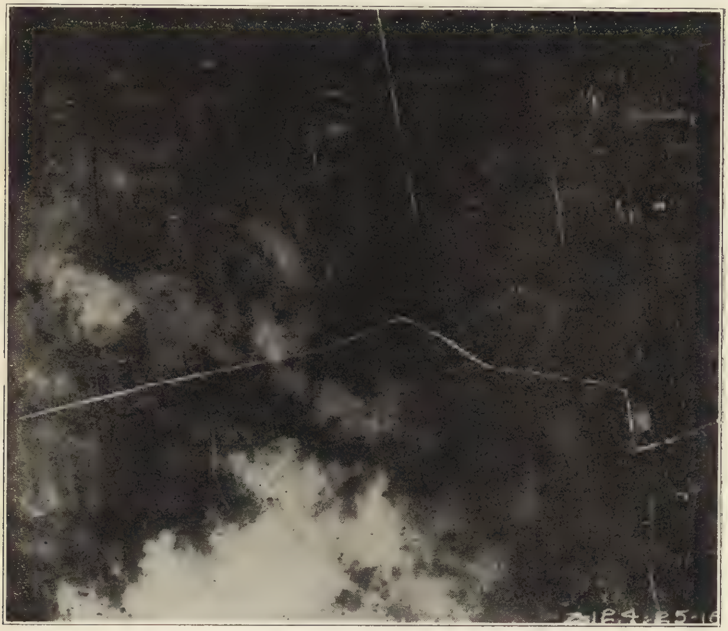

Fig. 3B

Showing elimination of haze

that objects are visible by virtue of the light which they reflect, it is more precise to say that such visibility is due to the *differences* in the light which they reflect. This is evident if we consider an object of exactly the same color and brightness as the background against which it is viewed. Under such conditions the object is indistinguishable from the background and hence is invisible. Difference in either the intensity or the quality of the light is sufficient for the production of visibility. Intensity differences cause objects to

appear of various brightnesses, while variations in the quality of the light are perceived by the eye as differences of color.

Since the photographic process can not reproduce color, variations of quality are translated by it into brightness differences, the translation depending upon the color sensitiveness of the photographic materials. Variations of brightness are produced in nature either by differences in the reflecting power of surfaces subject to the same illumination or by differences in the illumination of various parts of a surface having a uniform reflecting power. Black ink reflects less light than white paper, and so with the same light falling on each there is a difference in brightness by which ink marks are distinguishable. On the other hand, if a plaster cast be lighted from one side, parts of the surface will be in shadow, and although the whole cast has the same reflecting power, there will be differences in brightness by virtue of which the details of the cast will be visible.

Therefore any diminution of the contrast between the different parts of a subject will diminish the ability of the observer to discriminate detail; and, since the object of aerial photography is the discrimination of detail in the subject photographed, the effect of haze is to produce a most serious loss in the efficiency of the process. The study of haze and of the best methods of diminishing its photographic effects thus becomes of primary importance for aerial photography.

The factors in aerial photography which can be controlled are:

1. The color of the light by which the photograph is taken;
2. The properties of the sensitive material used for making the negative;
3. The exposure given;
4. The developer and the time of development.

Of these factors, the most important is 1, but the choice of the color to be used is necessarily conditioned by the color sensitiveness of the sensitive materials available.

As will be seen later, light of short wave-lengths is much more strongly reflected by the small particles of the air than is light of longer wave-lengths, so that the longer the wave-length—that is, the redder the light used—the less will the haze effect be. Unfortunately, photographic materials are much more sensitive to light of short wave-lengths than to the longer waves, and the red and yellow light can, therefore, be employed only on materials sensitized especially for the pur-

pose and even with such materials only with an increased exposure.

Since the exposure which can be given in aerial photography is limited by the conditions of the work, the use of red or yellow light for the elimination of haze is also limited, and it becomes of importance to ascertain how far the improvement in contrast can be effected by the correct selection of factors 2, 3 and 4, in spite of the greater importance of the factor of color.

The work dealt with in this monograph was undertaken in order to determine primarily the types of photographic materials most suitable for photography through haze and the conditions under which those materials would be used, and, secondarily, to study the occurrence, distribution and value of haze.

It was decided at the outset that the problem could best be attacked in three definite stages.

(1) The extent and distribution of the haze and its spectral quality can be determined only by observations from aeroplanes under different weather conditions and at different altitudes; and since the quality must be considered from a photographic point of view, it was decided to use photographic methods for this investigation.

(2) The behavior of photographic materials when used for photographing a subject having a general veiling haze superimposed was studied in the laboratory by means of a so-called "haze cabinet", in which a camera was arranged to photograph any set of diagrams required, while by means of a semi-transparent mirror before the lens a uniform intensity from a separate light source could be superimposed upon the image. With this apparatus it was possible to investigate the advantages and disadvantages of different photographic materials under various haze conditions (amounts of veiling haze), and to determine the conditions of exposure and development which would give the best results with a given amount of haze. The calibration of this apparatus on the basis of the data obtained from the air as to the amount of veiling haze present under varying conditions, enables decisions to be made in the laboratory concerning the materials which should be used for field work, and the treatment which those materials should receive.

(3) The utility of various materials from the point of view of photographing through haze having been investigated by means of the haze cabinet, these materials were subjected to the standard sensitometric methods of investigation. The

properties shown by the sensitometric data were correlated with the behavior of the materials in the haze cabinet, thus making it possible to deduce from the ordinary sensitometric tests the suitability which a given material has for aerial work.

Only a part of the work planned was accomplished. Methods for the study of haze were devised, and some preliminary measurements from the air were made. A much more complete study, correlated with meteorological data, is, however, necessary, and should be undertaken in the interests both of meteorology and of aerial photography.

The types of sensitive material suitable for aerial photography were determined and criteria for their suitability established, as were also the conditions of exposure and development which give the best results.

CHAPTER II

The Methods of Photographic Photometry

When a photographic material such as a film or plate is exposed to an increasing series of intensities, the deposit produced upon development depends upon the intensity acting during exposure, so that if a strip of the material is exposed in steps, these steps are represented by a series of densities in the developed plate. The property of the developed density which is of interest from the photographic point of view is its light-stopping power. This can be measured by means of a photometer, in which the light transmitted through the clear portion of the image is equalized, by means of some optical device, with that transmitted by the density to be measured.

When the densities thus measured are plotted against the exposures, a logarithmic scale of exposures being chosen, it has been found that a curve of the general type shown in Fig. 4 is obtained. Throughout a considerable portion of its range, the rise in density is seen to be proportional to the logarithmic increase in exposure, and through this portion a straight line can be drawn corresponding to the equation

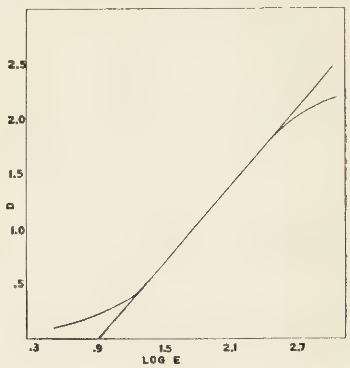

FIG. 4

$$D = \gamma (\log E - \log i),$$

where γ represents the slope of the straight line—that is, the tangent of the angle which it makes with the exposure axis—and $\log i$ is the intercept on the exposure axis.

This characteristic curve of a photographic material was first described by Hurter and Driffield, who found that for normal development the point of the intercept of the straight line on the exposure axis remains invariable, and that a change in the time of development corresponds only to a change in the value of γ; that is, of the slope of the straight line. For this reason, the exposure i corresponding to the intercept $\log i$ was called by them the inertia of the photographic material, while γ was termed the development factor.

According to Hurter and Driffield the sensitiveness of a material is defined by dividing the value of the inertia into some constant. In the lower portion of the characteristic curve before the straight line is reached, the curve is convex to the exposure axis, increasing in slope from a zero value to that of γ. This region was termed by Hurter and Driffield the region of *under-exposure*, while the corresponding region, where the curve becomes concave to the exposure axis and the slope diminishes from γ until it finally becomes zero, was called the *over-exposure* region. These names arise from the fact that it is only through the straight-line portion of the curve that the opacities of a negative correspond inversely to the brightnesses of the original subject, and, consequently, it is throughout this region that the reproduction of the tones of the subject is correct in a negative. Any portion of the scale of brightnesses which falls upon the under- or over-exposure portions of the curve produces an incorrect and distorted rendering of the scale of tones.[1]

The whole characteristic curve can, of course, be expressed by means of a mathematical equation, and several such equations have been proposed by photographic workers.[2] Such equations are integrations of differential equations derived from assumptions as to the absorption of light by the film and as to the distribution of sensitiveness among the grains composing the sensitive emulsion.

The characteristic curve can obviously be used for the translation of the density of any photographic deposit into the corresponding intensity by which it was produced. Thus, if we photograph from the air two areas such, for instance, as a wooded area and an open field, and impress upon the plate before development a known scale of intensities, then, after development, we can measure the densities of the known scale, draw the characteristic curve, measure the densities corresponding to the areas in which we are interested, and by interpolating these densities upon the curve deduce the light intensities corresponding to the areas.

Photographic photometry thus consists of the determination of the intensity of the exposures to be measured by interpolation of the densities produced by them on a scale of densities produced by known intensities. It is obvious that the accuracy of photometric measurements made in this way will depend upon the scale of densities from known exposures

[1] Jones, L. A., On the theory of tone reproduction. J. Frankl. Inst. **190**: 39. 1920.

[2] Ross, F. E., On the relation between photographic density, light intensity, and exposure time. J. Opt. Soc. Amer. **4**: 255. 1920.

being produced under conditions which are exactly the same as those under which the densities to be measured are produced. We must eliminate (1) variations due to the material—i. e., irregularities in sensitiveness, thickness of coating, etc.; (2) variations due to the treatment—i. e., differences in developing the intensity scale and the densities to be measured; (3) variations in the intensity or time of exposure of the two scales (it is not justifiable to assume that time and intensity, the two components of exposure, are reciprocally equivalent); (4) variations due to the quality of the light. The scale must be made by light of the same wave-length as that which produced the exposures to be measured. Let us consider these factors in turn:

1. In order that *variations in the material* may be reduced to a minimum, it is advisable to impress the intensity scale and the densities to be measured upon the same plate or film. This automatically eliminates variations due to different times of development. Where this is not possible, the exposures should be made on material from the same package, which receives identical treatment before and after exposure. When exposures are made upon the same material, the only variations likely to occur are due (1) to differences of sensitiveness in different parts of the material, generally produced during the drying process. Thus there is usually an area of somewhat greater sensitiveness around the edges of the plates than in the middle; and (2) variations in the thickness of the coating such as may occur, especially with plates, owing to waviness of the glass on which the emulsion is coated.

In the course of a study of the uniformity which may be expected in different parts of the same photographic plate, the average deviation for white light was found to be of the order of four per cent, and the maximum deviation about eight per cent. When panchromatic plates were used with color filters, and the plates exposed to red, green, and blue light, greater deviations were observed for red than for green, and for green than for blue light. The maximum deviation in this series of experiments was ten per cent for blue light and fifteen per cent for red light. It is clear that the average precision of a single measurement upon plates by the methods of photographic photometry cannot be expected to be greater than five per cent, owing to variations in the sensitiveness or coating of the material. With film, the precision is somewhat greater, as the emulsion is coated upon a wide band of support, and differences in sensitiveness due to drying conditions are much less likely to occur than in the case of plates. The

waviness characteristic of the glass on which ordinary plates are coated also does not occur with films. The average deviation for portrait film is found to be three per cent, the maximum deviation approximately six per cent, both these measurements being made to white light.

2. *The Effect of Treatment.* During development, the slope of the straight-line portion of the characteristic curve (γ) increases, the straight line rotating around the inertia point. The slope can not, however, be increased indefinitely by increase of development, as γ increases from a zero value to a limiting value, γ_∞, which depends upon the nature of the material. See Fig. 5. The increase of γ with time is exponential, corresponding to the equation $\gamma = \frac{\gamma_\infty}{1-e^{-kt}}$ or, in its logarithmic form,

$$K = \frac{1}{t}\log\frac{\gamma_\infty}{\gamma_\infty - \gamma}.$$

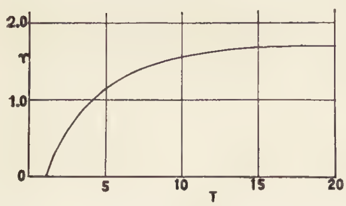

FIG. 5

The value of γ_∞ may be as low as 1.5 for fast materials, such as portrait plates or film; for the average plate used in general photography it will vary from 1.8 to 2.3; while for process plates, having the greatest contrast, it will generally exceed 3.0. The constant K which, together with γ_∞, determines the velocity of development and represents the velocity constant of the chemical reaction, is dependent upon the nature and concentration of the developer, upon the temperature, and upon the material.

It is convenient to adjust development so that a γ of unity is obtained in a time of about five minutes. When the developer contains a soluble bromide, the intercept of the straight-line portion of the characteristic curve upon the exposure axis is no longer fixed, but decreases during development to a limiting position corresponding at γ_∞ to the normal position obtained in the absence of bromide. (Fig. 6.) It can be shown that all the straight-line portions of the curves obtained with different times of development in a bromided developer meet at a point, just as with a non-bromided developer; but this point is no longer situated upon the exposure axis, but is below it. The depression is a measure of the

effect of the bromide upon the reduction potential of the developer.[1] (Figs. 7A and B.)

From this discussion of the variation of the characteristic curve with development it will be seen that in photographic

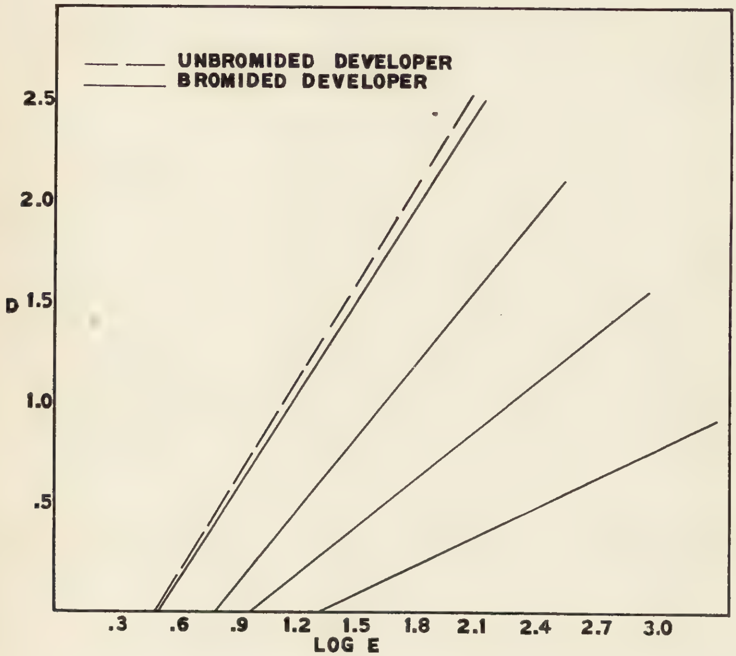

FIG. 6

photometry it is essential to obtain uniform development for all densities which are to be compared with each other. It is especially necessary to avoid accidental development effects such as may be produced by eddy currents in the developer, by stationary waves, or by local exhaustion. In spite of all precautions there are certain defects produced by the effect of the surrounding densities upon the concentration of the developer, which may affect the value of density determinations by photographic methods. These have been studied recently by a number of workers, to whose papers the reader is referred. In the work on aerial photography,

[1] Nietz, A. H., The theory of development. Monograph No. 2.

it was believed that these effects were not of sufficient importance to require special investigation, and they were ignored.[1]

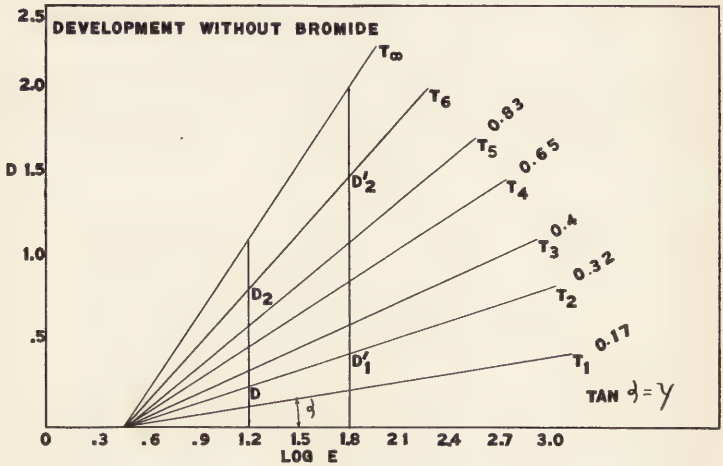

Fig. 7A

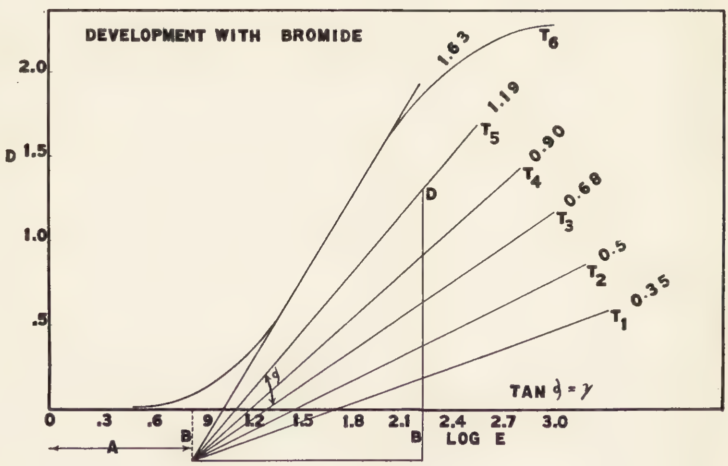

Fig. 7B

[1] Ross., F. E., The mutual action of adjacent photographic images. Astrophys. J. **53**: 349. 1921. Eberhard, G., Ueber die gegenseitige Beeinflussung benachbarter Felder auf einer Bromsilberplatte. Physik. Zeits. **13**: 288. 1912.

3. Up to the present, *the exposure* has been treated as if it were a definite quantity, but an exposure necessarily involves two factors, the intensity of the light acting and the time for which it acts. Thus,

$$E = f \cdot I\, t.$$

The simplest assumption with regard to these two factors is that the variation of one of them can be exactly compensated by a reciprocal increase in the other, so that we can write

$$E = I\, t.$$

On investigation it is found, however, that this simple relation is not true, especially when t is large, and for values of t exceeding 100 seconds the relation certainly can not be held to be valid. Schwarzschild suggested that a closer approximation to the relation would be given by the relation

$$E = I\, t^p,$$

but it is doubtful whether this is any more than a further approximation. As Ross has pointed out, if this equation can be assumed to hold it is easy to determine p, since if we impress on a plate two scales, one varying the time and the other varying the intensity, then

$$p = \frac{\gamma \text{ for the time scale}}{\gamma \text{ for the intensity scale}}.$$

In photographic photometry, however, the difficulty can be avoided completely by using an intensity scale when measuring intensities, since in this way the exposures corresponding to given densities are strictly comparable as regards intensity. It must be remembered, however, that the function is probably dependent upon the absolute time of exposure, so that not only must the relative intensity scale be correct, but the absolute intensity must be of the right order, since if the densities to be measured were impressed, for instance, in 1/100 of a second by exposure from an aeroplane and the density scale was impressed by an exposure of several minutes in the laboratory, the two intensity scales would not necessarily be comparable.

4. *Variations in the Quality of the Light.* The characteristic curve varies in shape and in slope with the wave-length of the light producing it. This is shown in the range of wave-lengths used with ordinary plates in Fig. 8, which is taken

from a paper by F. E. Ross.[1] It is seen that both the slope and the shape of the curve vary considerably with the wave-length of the light. The general relation between γ and wave-length is shown in Fig. 9 which is also from Ross's paper. It is evident that the variation of γ with wave-length is so considerable that photometric measurements can be relied upon only when the exposure scale is made with light of exactly the same quality as that by which the densities to be interpolated were produced. This is well shown in the following experiment:

A plate was exposed through three color filters, one transmitting light from 460$\mu\mu$ upwards, the second from 510$\mu\mu$

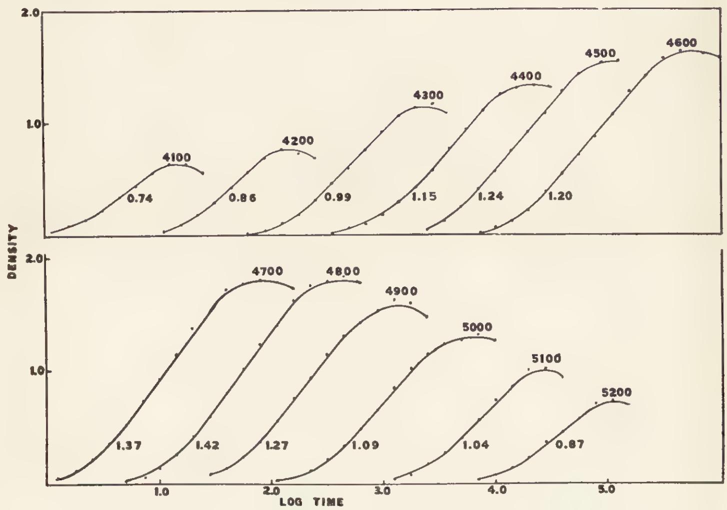

FIG. 8

Variation of the characteristic curve with wave-length of light

upwards, and the third from 555$\mu\mu$ upwards. The exposures were made to a tungsten glow lamp with an intensity scale of neutral densities, the lamp being run at different currents, thus changing its spectral distribution:

		γ	
Current	Filter No. 1	Filter No. 2	Filter No. 3
1.5 amps.	1.67	1.79	1.87
1.8 amps.	1.43	1.61	1.80
2.1 amps.	1.35	1.54	1.75

[1] Ross, F. E., Photographic photometry and the Purkinje effect. Astrophys. J. **52**: 86. 1920.

An increase of current in the glow lamp shifts the maximum of the spectral distribution curve to shorter wave-lengths, and it will be noticed that γ decreases as the current is increased and increases as the wave-length of the filter absorption limit increases, so that the highest γ is obtained with the reddest filter at the lowest current, and the lowest γ with the lightest filter at the highest current. This experiment shows the great errors which may be introduced by changes in the color of the light by which the scale is impressed upon the materials, and, as will be seen in Chapter III, that very special precautions are necessary to ensure that the comparison scale is impressed by light of exactly the same quality as that reflected from the objects to be photographed.

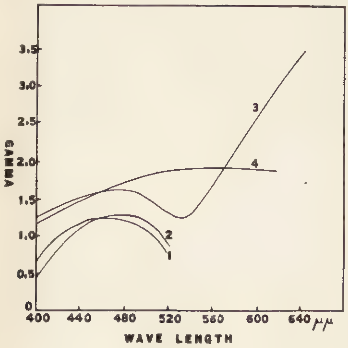

FIG. 9

1 Ord. plate 3 Pan. plate
2 Ord. plate 4 Ortho. plate

METHODS OF MEASUREMENT

Exposure scales are produced by instruments known as *sensitometers*, and they are expressed usually in c.m.s., the unit representing the light of a one-candle-power standard lamp at a distance of one meter for one second. No definition of the photographic candle is accepted generally at the present time, and since light sources which are visually identical have quite different photographic effects, according to the quality of the light emitted, there can be said to be no definite unit of exposure. Each laboratory adopts its own unit expressed in candle-power of some standard lamp such as the pentane lamp, an electric lamp burning at a given temperature, or an acetylene burner of a specific type. Fortunately, in the work under discussion, the absolute magnitude of the intensities was of no importance, and the exposures could be expressed in arbitrary units without difficulty.

Sensitometers can be of the forms which impress either a time scale or an intensity scale, and these scales can be impressed either continuously or intermittently.[1] The intermittent sensitometer varies the exposure on the plate by means of a rotating sector wheel in which angular openings

[1] Jones, L. A., A new non-intermittent sensitometer. J. Frankl. Inst. **189**: 303. 1920.

are cut, permitting the differential transmission of light in some known ratio. This wheel, which is mounted at one end of the sensitometer box, is rotated at a constant speed in front of the plate during exposure. Immediately behind it is an opening in which the plate holder carrying the plate is inserted. The light source is mounted at the other end of the box and at a definite distance from the plate holder. The instrument, comprising rotating sector wheel, light source, and plate holder, is enclosed in a light-tight housing so that the only light incident on the plate during exposure comes from the standardized light source and passes through the opening in the sector wheel as it rotates in front of the plate. Exposures in this type of sensitometer are incident intermittently, and investigation has shown that the resulting densities are lower in value than those from an equal, continuous exposure, especially for low exposure values.

In non-intermittent sensitometers, the sensitive material is supported in a frame equipped with a device for screening it in successive steps. The movement of the screen is so timed that consecutive steps receive exposures whose times vary as powers of some convenient number. As in the intermittent type, this causes the logarithms of the exposures to differ by constant amounts, and they can, therefore, be plotted as abscissae equally spaced. The intensity of the light falling on the plate can be varied by changing the distance between the source and the plate or by altering the source itself.

A method of intensity-scale sensitometry which varies the exposure by changing the light intensity rather than the time of exposure consists of placing in contact with the emulsion of the photographic plate a tablet divided into several sections of consecutively increasing density. By exposing through this tablet for times comparable with those used in the case to be investigated, the danger of exceeding the reciprocity limits of the exposure formula may be avoided. The tablet also forms a means of obtaining definitely graded exposures in the field, or under circumstances where the elaborate apparatus for the other method can be neither obtained nor manipulated. The chief objection to the tablet method is a possible lack of neutrality of the superposed material.

If the light intensity is not merely cut down but selectively absorbed, the photographic plate will receive light of a different color from that given by the source, and this difference will change as we proceed from one density to another in the tablet. It is quite possible, however, to form tablets which are neutral within the limits of photographic detection. The tablets

used in the field work described in this monograph were made by exposure in the laboratory with the non-intermittent type of sensitometer and developed in monomethyl paraminophenol (Elon), a developer particularly suitable for producing neutral deposits. The resulting tablets were tested for selectivity of transmission by comparing exposures through them with exposures in the laboratory sensitometer. No effects attributable to color greater than the experimental error could be detected. The transmission of these tablets was then measured both by means of a photometer and photographically, and used as a factor to define the amount of light transmitted by each step.

The density of a photographic plate was defined by Hurter and Driffield as the logarithm of the opacity, the opacity being the reciprocal of the transparency of the plate. Thus, if I be the intensity of the incident light, and I_1 the intensity of the light transmitted, then

$$\text{Transparency} = \frac{I_1}{I} = T;$$

$$\text{Opacity} = \frac{1}{T} = \frac{I}{I_1} = O;$$

$$\begin{aligned}\text{Density} &= \log_{10} O: \\ &= \log_{10}\frac{1}{T}; \\ &= \log_{10}\frac{I}{I_1} = D.\end{aligned}$$

Thus, when $D = .301$, $O = 2$, and $T = .5$; $D = 1$, $O = 10$, and $T = .1$; $D = 2$, $O = 100$, and $T = .01$; $D = 3$, $O = 1000$, $T = .001$, and so on.

It will be seen that if we assume the silver deposit to follow Beers' law, D will be proportional to the mass of silver in unit area; and it has been shown experimentally that this relation holds with great accuracy for photographic deposits, the relation between D and the mass of silver per square centimeter being termed the photometric constant. For normal emulsions and a density of unity, there corresponds a mass of .1 milligram of silver per square centimeter. The measurement

of the density can be made with any of the usual devices for comparing light intensities.[1]

Many different types of photometers, microphotometers, and spectrophotometers have been designed and used for the measurement of photographic densities. In these instruments, numerous means have been used for varying the intensity of the light, such as adjustable slits, polarizing and analyzing nicol prisms, and calibrated neutral gray wedges. In most of the instruments one light source is used to illuminate both halves of the photometric field, so that any variation in the intensity of the source during the course of a set of readings does not affect the determinations.

The essential requirements in any density-measuring instrument are: (1) a photometric field consisting of two parts so arranged that when they are of the same brightness the dividing line almost or entirely disappears; (2) a means of illuminating the two parts of the field uniformly and equally; (3) a means of placing the density to be measured in the path of the light illuminating one part of the field; and (4) a means of cutting down the intensity of the light illuminating the other part of the field to a variable and precisely known extent.

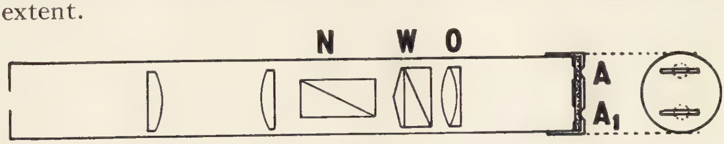

FIG. 10

Martens Photometer

Certain forms of polarization photometers are quite sensitive, free from systematic errors, and extremely convenient for measuring the coefficients of transmission for white light. One of the best and simplest of these and the one used in this investigation was the Martens (Fig. 10). Light from the source, a tungsten glow lamp, enters at the two apertures, A and A_1, is rendered convergent by O, and is polarized by a Wollaston prism W. The resulting circular field is divided along the diameter by a line which practically disappears when a balance is obtained. A nicol prism N is interposed in the path of the double beam. When the prism is placed at an angle of 45° to the planes of polarization, equal amounts of light are transmitted. Rotating the prism reduces the transmission of one beam and

[1] Sheppard, S. E., and Mees, C. E. K., Investigations on the theory of the photographic process.

increases that of the other, the ratio of transmitted intensities varying as the square of the tangent of the angle which the prism makes with the position of complete extinction. The two halves of the field are illuminated uniformly and equally by light passing through a disk of opal glass placed in front of the light source. The photographic plate is placed on the opal glass in such a manner that the density to be measured covers one half of the field, while the other half remains clear. The instrument as a whole is extremely sensitive and reliable.

The deposit in a photographic emulsion consists of a large number of small particles of silver, and this deposit diffuses or scatters some of the light incident upon it, the amount scattered depending upon the size of the grains and their distribution in the film. The transmission of such a density for a specular beam will therefore consist partly of specular light and partly of scattered light, and since photometers necessarily measure only the light leaving the density over a small angle, the light scattered by the density will be counted as if it were absorbed. As a result of this, a density measured by light which is approximately parallel will give a higher reading in the photometer than the same density measured by light which is completely diffused before it enters it, since in the first case light will be lost by scattering, whereas a completely diffuse light cannot further be fully scattered. This subject was investigated by Callier,[1] who termed the relation between the density measured by parallel light and that measured by scattered light Q, and showed that the value of Q varies from slightly above unity for the finest grained and most transparent deposit to a value as high as 1.6 for the coarsest and most scattering deposits. Callier showed that the most practical and consistent method of measuring densities is to use completely diffuse illumination. This is accomplished by making the measurements with the emulsion side of the photographic plate in contact with a uniformly illuminated piece of pot opal glass. By doing this, the results obtained with different photometers are comparable, and the conditions closely approximate those which exist when contact prints are made from negatives.

If the area of the density to be measured is too small to cover the photometer aperture, it is necessary to project a magnified image of it on to a screen placed in direct contact with the aperture. A microphotometer of this type was used in part of the work.

[1] Callier, A., Absorption and scatter of light by photographic negatives. Phot. J. **33**: 200. 1909.

COLOR SENSITIVE MATERIALS

Since the objects of this investigation included a study of the color of atmospheric haze and the possibility of its elimination by the use of suitable light filters, the materials used were necessarily color sensitive; that is, sensitive to light of longer wave-length than $500\mu\mu$, which is the limiting wave-length of sensitiveness for normal bromo-iodide emulsions. Such color sensitiveness is produced by the use of sensitizing dyes which, when added to the emulsion, stain the silver bromide grains and render them sensitive to light of the wave-lengths which are absorbed by the dye used.

Two groups of dyes are used in color sensitizing, and consequently color sensitive materials fall in one of two general classes: (1) Dyes of the fluoresceine series, notably the sodium salt of tetra-iodo-fluoresceine, generally known as erythrosine, sensitize silver bromide very strongly for the yellow-green rays which they absorb, and are generally used for the orthochromatic plates of commerce. These dyes are acid, being used in the form of the soluble sodium salts, and their action upon the emulsion is enhanced very much by the presence of ammonia. (2) On the other hand, there is a series of basic dyes produced by the condensation of quinoline with quinaldine derivatives which are also powerful sensitizers for photographic emulsions and which confer a wide band of sensitiveness stretching through the whole of the green and far into the red regions of the spectrum. Photographic materials, sensitive to practically the whole of the visible spectrum, are known as panchromatic. They may be made either by the addition of the dyes to the emulsion or by treatment of the dry plates with a solution of the dye. The cyanine dyes have been known for many years to sensitize photographic plates, but they have the disadvantage that the materials sensitized with them fog easily and have very poor keeping qualities. In 1897 Miethe discovered a dye which shows a strong sensitizing action on silver bromide without the disadvantages displayed by the cyanine dyes. This dye, Ethyl Red, was the first representative of a new series of dyes known as isocyanines, which are isomeric with the cyanines, and are produced by condensing together ethiodides of quinoline and quinaldine derivatives.

The investigation of these dyes was extended by E. Koenig, who supplemented Miethe's first dye, known as Ethyl Red, by other dyes made from substituted quinaldines and quinolines, which were placed on the market under the trade names

of Orthochrome T, Pinaverdol, and Pinachrome. Later, Koenig discovered that by condensing the dye components in the presence of formaldehyde, a new series of dyes was obtained, the first of which was placed on the market under the name of Pinacyanol, this dye displaying extraordinary red sensitizing power and showing a strong maximum of sensitiveness at $645\mu\mu$. This new series of dyes has recently been termed the carbocyanines. Still other dyes of a similar type but belonging to a different series, have sensitizing power in the extreme red and even in the infra-red.[1] For practical purposes the most useful dyes are Pinacyanol, Kryptocyanine and one or two of the isocyanines such as Orthochrome T, Pinaverdol, or Pinachrome, the particular isocyanine to be selected depending upon the characteristics of the emulsion. These dyes, which were made only in Germany before 1914, were duplicated in the allied countries during the war.

Since exposures from the air are necessarily very brief, and since, as will be shown in the course of this monograph, the use of strongly colored filters is advantageous, every effort was made to increase the color sensitiveness of the materials available, and the sensitizing of materials and methods of measuring their color sensitiveness were extensively studied. Numerous improvements were made in the preparation of the materials, notably in panchromatic plates and films sensitized with pinacyanol and the isocyanine dyes. Small quantities of highly sensitized materials were made by bathing finished plates in dye baths containing a large amount of alcohol and some ammonia, but equally good results were found to be obtainable by the use of materials sensitized in the emulsion and hypersensitized by treatment with a dilute bath of ammonia before use.[2] At the present time, plates and films of sensitiveness sufficient for aerial photography when used with strong yellow filters are commercially obtainable. If red filters are to be used, hypersensitizing with ammonia gives excellent results.

The measurement of the color sensitiveness of the materials can be accomplished either sensitometrically or by means of a spectrograph. A simple grating spectrograph using tungsten

[1] Adams, E. Q., and Haller, H. L., Kryptocyanines. A new series of photosensitizing dyes. J. Amer. Chem. Soc. **42**: 2661. 1920. Mees, C. E. K., and Gutekunst, G. O., Some new sensitizers for the deep red. J. Ind. Eng. Chem. **14**: 1060. 1922.

The Kryptocyanines were not discovered until after the work described here was completed. Kryptocyanine sensitizes strongly with a maximum at $770\mu\mu$ and should be very suitable for aerial photography, but owing to the falling off in the energy of the solar spectrum beyond $700\mu\mu$ and to the strong absorption bands between $760\mu\mu$ and $780\mu\mu$ it is very difficult to get sufficient exposure.

[2] Burka, S. M., Hypersensitizing commercial panchromatic plates. J. Frankl. Inst. **189**: 25. 1920.

light as the source, and a wave-length scale held in front of the sensitive plate so that it is impressed upon the plate at the time of photographing a spectrum are all that are required, but it is convenient to have a neutral-tinted wedge in front of the slit by means of which a curve of the sensitiveness of the material is drawn automatically so that the position of the sensitive bands can be seen at a glance (Fig. 11). The spectrograph used for this purpose is known as a *wedge spectrograph.*[1]

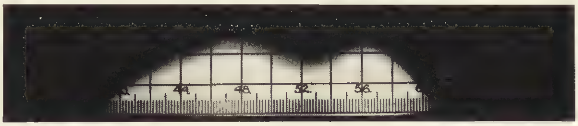

FIG. 11

For quantitative measurements, however, a more satisfactory method of determining sensitiveness is to use a time or intensity scale sensitometer and to make exposures through color filters transmitting known regions of the spectrum. A convenient set of filters is that known as the standard tricolor set of filters used for color photography, the transmission limits of these filters being as follows:

A. 580 $\mu\mu$ to infra-red;
B. 475 $\mu\mu$ to 635 $\mu\mu$;
C. 350 $\mu\mu$ to 510 $\mu\mu$.

With such filters in the sensitometer, the material is exposed in four strips, one without a filter and one each with the three color filters, the increase of exposure necessary to get the same density through each filter being measured.

Since the characteristic curves are not parallel to each other (Fig. 12), it is necessary to decide on the density and development at which the comparison is to be made, and for the sake of precision the plate is developed so that the curve of the plate without a filter shows a γ of unity, and the exposure necessary to produce a density of unity behind each filter is then used for computing the increase of exposure required by the filter. These increases are known as the *filter factors.* As a material is made more color sensitive, the factor for the blue filter naturally increases, and the factors for the red and green filters diminish. The filter factors for the tricolor filters form what is generally known as the *filter ratio.* For

[1] Wratten, S. H., and Mees, C. E. K., The wedge spectrograph. Brit. J. Phot. **54**: 384. 1907.

the standard Wratten tricolor filters A, B and C, the ratios of plates made before the war were generally

Blue, 6; Green, 12; Red, 16.

These ratios were improved by intensive work until for an ordinary plate a ratio of

10; 10; 10

may be considered normal, and by hypersensitizing a ratio of

12; 8; 6

may easily be obtained. However, if this resulted in a general loss of sensitiveness, it would present no advantage for aerial photography. A more useful record of color sensitiveness can

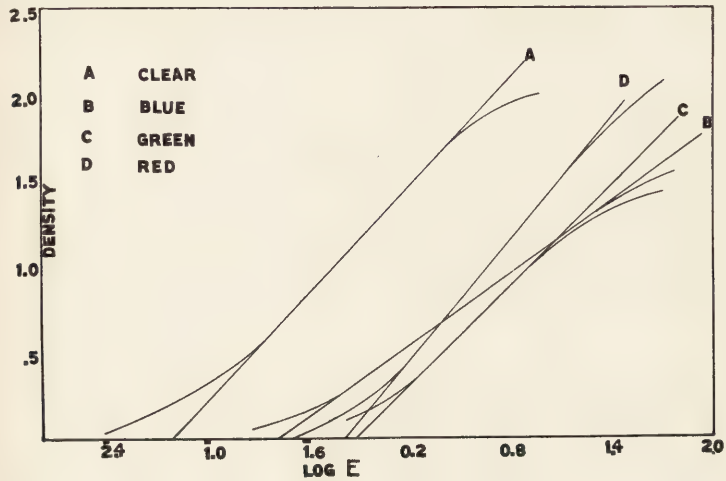

FIG. 12. Characteristic curves for different filters

be obtained by stating the effective speed through the filters, this being found by taking the total H. and D. speed to white light and dividing it by the factor of the filter concerned. Thus, if we have a plate of speed 240, and it is to be used with a No. 12 Wratten filter having a factor of 6, the effective speed will be 40, while with the red filter having a factor of 10, the effective speed will be 24. It may be quite possible to make a similar plate with a factor for the red filter of only 6, but with a speed reduced to 120 by the excessive amount of dye used. It will be seen that the effective speed of this through a red filter will be only 20 as compared with 24 for the first plate, so that the additional dye would be a disadvantage for aerial photography, although the ratio might at first sight suggest that it would be advantageous.

CHAPTER III

The Measurement of Aerial Haze

Haze is the optical turbidity of the atmosphere. It may be caused by dust, smoke, water vapor, irregular temperature distribution, or even by dry air. In fact, any atmospheric material which tends to diminish the transparency of the space it occupies may be said to be a source of haze. There are many types of haze. At times it is stratified near the ground or at high altitudes, and at other times it extends uniformly to a great height. Its quality or color also varies, not only with the varying sources of haze but also with the size of the suspended particles it may contain. Haze, therefore, is due to a light-scattering medium, which creates a veiling glare between the camera and the subject to be photographed. It superposes a uniform light intensity over all parts of the subject, causing not only a brightening of it but also a great reduction in its contrast.

The determination of the distribution, the quantity, and the quality of haze is possible only by observations from aeroplanes at various altitudes and under different weather conditions, and, since these important factors must be considered from a photographic viewpoint, photographic methods are employed. Therefore, it is necessary to frame a definition of haze in terms of its measurable effects upon the developed photographic material. This definition is based upon the two obvious effects. The suspended materials in the atmosphere scatter sunlight and hence send back light to the camera, which adds to the exposure creating an image of the subject: these materials also subtract somewhat from the light reflected upward from the ground. Although these tendencies work in opposite directions in their effects upon the exposure which the photographic plate receives, there is no reason for assuming that they exactly counteract one another. The absorption or subtractive effect of the haze is concerned with much less light and is no doubt of less importance.

Assume that the subject to be photographed contains objects which are white, gray, and black. Let E_w, E_g and E_b, respectively, represent exposure values, in candle-meter-seconds if convenient, due to these objects. When the camera is near the ground, no haze effect except, of course, the general decrease in ground illumination, is involved. At any altitude A let the exposure due to the light from the haze be e and let h'

be the ratio of e to E_w so that

$$h' = \frac{e}{E_w} \text{ or } e = \frac{h'}{E_w}$$

Therefore, the total exposure giving rise to the image of the white portion of the subject will be

$$E_w\,(1-a) + h'\,E_w$$

where $(1-a)$ represents the absorption or subtractive effect of the haze. Similarly, for the black portion of the subject the total exposure is $E_b(1-a) + h'E_w$ and for the gray $E_g\,(1-a) + h'E_w$. This is true since the relative amounts subtracted and the absolute exposure added are identical for the white, gray, and black portions of the subject. Therefore, if on a photographic material, exposed at any altitude, the ratio of exposures on the white and black objects respectively is K, then

$$\frac{E_w\,(1-a) + h'\,E_w}{E_b\,(1-a) + h'\,E_w} = K;$$

or, dividing both numerator and denominator by $Ew(1-a)$,

$$\frac{1 + \dfrac{h'}{(1-a)}}{\dfrac{E_b}{E_w} + \dfrac{h'}{(1-a)}} = K.$$

Now let $\dfrac{h'}{(1-a)} = h$, and further let $\dfrac{E_w}{E_b} = C$, which is measured from near the ground, say at an altitude of 500 feet

$$\text{Then } \frac{1 + h}{\frac{1}{C} + h} = K.$$

Solving for h

$$\frac{C - K}{C(K-1)} = h.$$

h is the haze effect expressed in such terms as are readily obtainable by photographic methods. The evaluation of C and K from plates exposed from various altitudes will be con-

sidered later. However, it may be remarked here that the

FIG. 13

Test objects are shown at lower right of picture

fraction $\frac{h' \quad E_w}{E_w \, (1 - a)}$ is the ratio of the exposure due to the

haze to the exposure given through the haze by the white portion of the subject; and this ratio is obviously equal to h, the haze effect. It is also evident that this evaluation of haze is independent of the actual brightness values—a fact which will be discussed later.

The three factors which it was desired to determine are the distribution, the quantity, and the quality of the haze. The method employed permitted the determination of all these from the same negative. The observations upon which the value of h and its distribution and color are based were made at Langley Field, Hampton, Va., during December, 1918, and January, 1919. Preliminary measurements, which aided materially in the establishment of the method finally adopted, were made from negatives obtained during the summer and fall of 1918 at Baker Field, Rochester, N. Y.

EXPERIMENTAL METHODS

The method consisted primarily in photographing three test objects—a black, a white, and a gray canvas, each 60 $\times$ 60 feet, of known reflecting power, spread in order upon level ground. (Fig. 13.) These canvases were photographically non-selective in reflection—a necessary condition since the quality of haze was one of the factors to be determined. The contrast between the white and the black canvas was approximately 1 to 8. The reflecting power of the three canvases was measured both visually and photographically, with the results given in the following table:

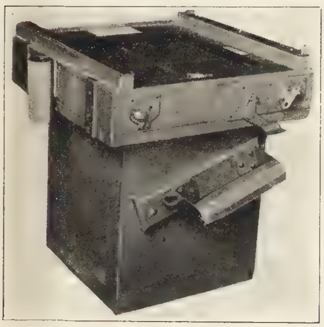

FIG. 14
Four-lens camera

TABLE I

Canvas	Reflecting Power: Photographic	Reflecting Power: Visual
White	56.0	64.8
Gray	17.5	20.1
Black	6.7	7.5

The cameras used were a four-lens type especially designed for this work. (Fig. 14.) Four IC Tessar lenses, each of ten-inch focal length, are placed at equidistant intervals in

the lens board. (Fig. 15.) The plate holder (Fig. 16), carries four 4 × 5 inch plates and is fitted with a notched template to make it possible to determine the position of a plate in the camera. Provision is made in each lens barrel for the insertion of color filters. The camera thus served as a photographic spectrometer, since the filters chosen were of such cut as to divide the spectrum into sharp intervals of known area.

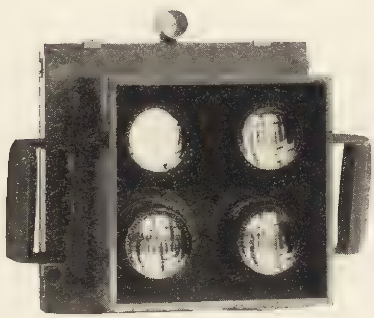

FIG. 15

Lens board

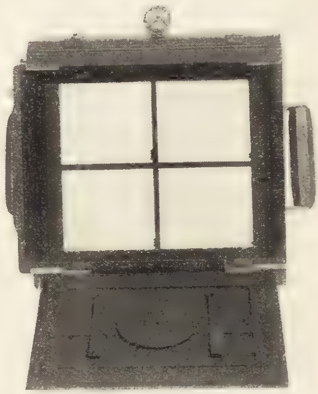

FIG. 16

Plate holder

In order to make the exposures received by the four plates as nearly equal as possible, the camera was calibrated. The stop or diaphragm values of the lenses, the speed of the shutter, and the relative total transmissions of the filters used were considered. The times of exposure for the four different slit widths and the six tension values of the focal plane shutter were determined by means of a shutter tester, which depended upon the operation of a tuning fork of known frequency. The values of exposure times obtained were plotted as functions of the distances moved by the slit, and the time value which corresponded to the value at the center of the plates was selected for use. The filter factors, which differed for the various types of photographic materials used, were defined as the ratio of exposures through the color filter and through a plain gelatine or dummy filter when both exposures produced a density of unity, the plates having been developed together for a time that gave a γ value of unity on the plate exposed through the dummy filter. These factors were obtained by means of a non-intermittent sensitometer, using identical

exposures on the two plates by adjustment of the distance from the source of light to the plate and the aperture over the source; so that when these factors of distance and aperture were considered, the two characteristic curves intersected at a density of unity when the γ of the plate exposed through the dummy filter was also unity. In this way it was determined, for example, that the filter factor for the Wratten and Wainwright No. 12 filter is 6.4 for a particular panchromatic plate, while for an orthochromatic plate the factor for the same filter is 8.5. Suppose, now, that the motion of the focal plane shutter is from lens A to lens B, and that A has a blue filter, B a dummy filter; and, further, that it has been found that for the desired slit and tension, the ratio of exposure times of A to that of B is as 3 to 2. The plate to be used is orthochromatic. Because of the motion of the aeroplane during the taking of the pictures, the shortest adequate time is to be used, and the stop of lens A is at $f/4.5$. The exposure at B must be 1/8.5 of that at A. Thus, $2/3 \times 1/X = 1/8.5$, and X will represent the fractional reduction to be produced by the stop. Therefore, the stop of lens B is set at $f/10.7$. With the stop values thus set for each filter to be used, the adjustment was checked by photographing a non-selective white diffusing surface in sunlight. Equal densities under the conditions of calibration as regards development were thus produced. The latitude of the material ordinarily covers small departures from precise equality in the resulting exposures.

The establishment of a numerical relation between density and exposure by interpolation on a scale of densities produced by known exposures was provided for by an intensity scale adaptable to field use. In this case, the intensity scale method consisted of printing a series of areas of known transmission and selectivity on the material used to photograph the test objects. One of the lenses was replaced by a glass plate supplied by the manufacturer of the lens and intended to duplicate it in absorption and reflection. In the corresponding section of the plate holder a 4×5 inch tablet was placed, having five sensitometric strips of ten sections each, of which the transmissions were known. Except for these strips, the tablet was opaque. Color screens were placed between each strip and the glass cover plate, the heaviest filter corresponding in position to the slowest shutter speed. The photographic material placed over the tablet could receive light only through the filters and accompanying sections. The exposure was made over the white canvas. The filters in the tablet were the same as those used in the three other lenses of the camera.

In the construction of this tablet it was desirable to have the log transmissions of the successive steps in any strip in arithmetical progression. These log transmissions differ by a constant from the log exposure given through them to the photographic plate, and when the characteristic curves for the observations are to be plotted, it is undesirable that the log exposure values should be unevenly grouped along the axis. In order that these log transmissions of successive steps on the strip should be uniformly separated, the corresponding exposures were calculated, as follows: In the coördinate system given in Fig. 17 the negative X axis represents the values of log transmissions of the tablet uniformly spaced. Since density equals log opacity

$$\left(\log \frac{1}{\text{transmission}} \text{ or } - \log \text{transmission}\right),$$

the same values and spaces transferred to the positive Y axis represent densities of the areas of the tablet. In the first quadrant is given the characteristic curve of the

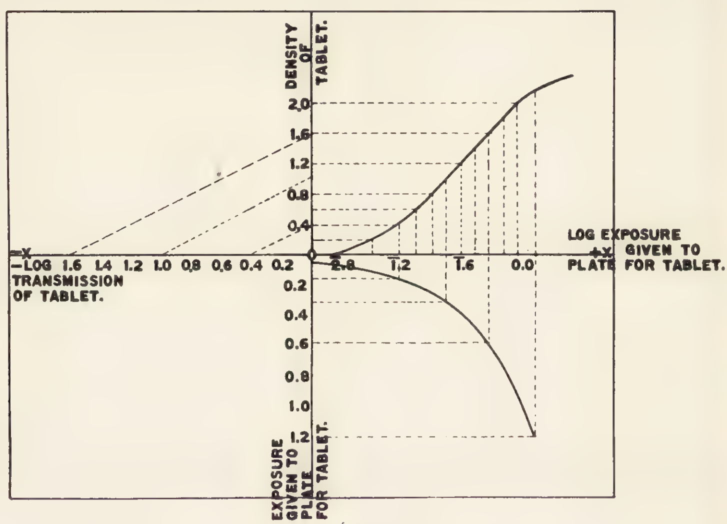

Fig. 17

plate and the time of development used, which plate is to be used to make the tablet. Now, if the equally spaced points along the positive Y axis are transferred to the positive X

axis, the new points will represent the various values of log exposure to be given in making the tablet. These points are again transferred to the negative Y axis by means of a logarithmic curve and the ordinates so determined are the exposure values which should be given the plate of which the characteristic curve is shown in the first quadrant, in order that the tablet have the transmissions desired. The determination of these values gives the exposure times to be used in the preparation of the tablets in the non-intermittent sensitometer. It appears, for example, that the first, fourth, seventh, and tenth steps are to be produced by exposures proportional to 0.16, 0.31, 0.58, and 1.2 respectively, or equal to these numbers in the units represented along the positive X axis. Many tablets were made in this way, with various highest density values. This was to compensate for the low total transmission values of the filters to be placed over the tablets.

For example, in order to produce a good H. and D. curve by the same time of exposure through the tablets, over which different color screens were used, it was necessary to place under the heaviest filter a strip of low densities, and under the lighter filters strips of higher densities. The tablets were developed in an Elon developer so as to produce a deposit of as little selectivity as possible. These tablets formed the intensity scale sensitometers used to interpret the air data. Exposures were made through the tablets (over which suitable color screens were placed as described), by light of the same quality as that by which the photograph was taken. Thus the density of any image in the aerial photograph is readily referable to the characteristic curve of the plate on which it is taken, and the ratio of exposure values derived. From these the value of the haze effect, h, is determined.

In this method of field sensitometry, then, it is possible to make exposures from a plane in the air at the time when the pictures of the test objects are taken. This could be done in the fourth section of the four-lens camera, the three remaining sections giving photographs of the test objects. This, however, makes the time of exposure for the sensitometric strip and for the image plates equal. As the altitude increases, the light through the plates or tablets comes from a wider and wider extent of territory. The region included at Langley Field would be at first only grassy fields, then some buildings, some woods, and finally areas of water would be included. Because of this fact the quality of the light would vary with altitude, and inasmuch as such variation directly influences the relation between density and exposure, it is to be avoided. Even

in the method finally adopted, where the exposures were made directly over the white canvas test object, the camera being held by an observer on the ground, some discrepancy is possible. The light by which the picture is taken from an altitude of 10,000 feet, for instance, might not be the same as that near the ground even when the picture and the sensitometric strip are made at the same time. To determine the effect of this difference upon the sensibility of the plate—that is, in technical terms, the effect of altitude on γ — flights over a uniform background, e. g., water, were made.

Laboratory methods usually endeavor to duplicate in the sensitometer the illumination out-of-doors on an average day, i. e., a combination of sky and sunlight such as one would receive by reflection from a perfectly white subject in natural surroundings. It is readily seen that the aerial photographer must discriminate between such sensitometric data and those which would be obtained from this illumination after it had been reflected from the various subjects encountered in the average terrain. Both contrast and color factors may differ widely for light reflected from water and from a plowed field. The following data bring out clearly the inadvisability of obtaining sensitometric data by exposing the strip in the four-lens camera simultaneously with the taking of the photographs of the test objects. The plates, the data from which are given in the following table, were exposed between a sensitometric tablet whose five strips were masked with five different color filters in a camera in which provision was made for distributing the light homogenously over the plate. Exposures were made at low altitudes in order to restrict the camera angle to a given type of subject.

TABLE II

VALUES OF GAMMA

Emulsion No. 2270 (Special Red Sensitive)

Subject	Dummy	Aero No. 1	Filter No. 12	No. 21	No. 25
Water	1.36	1.76	2.13	1.92	2.02
Woods	1.67	1.82	2.13	2.00	2.14
Hampton City	1.72	2.02	2.16	2.20	2.14
Light fields	1.80	1.91	2.13	2.14	2.24

Emulsion No. 1445 (Special Red Sensitive)

Subject	Dummy	Aero No. 1	Filter No. 12	No. 21
Marsh	2.24	2.14	2.14	1.80
Light fields	2.22	2.10	1.94	1.74
Hampton City	2.18	2.38	2.23	1.77

It will be noticed on examining the tables horizontally that these two emulsions behave very differently with change of color. No. 2270 shows an increase of γ with shift of color to red, whereas No. 1445 acts in the opposite manner. Water (Back River) was evidently the bluest of the subjects. For emulsion No. 2270, water produced the lowest γ and bare light fields the highest. An equally interesting table of results is formed from the filter factors of the above filters in the same cases. The filter factor is defined (as previously), as the ratio of the exposure necessary to produce a given density through the filter in question as compared with that through the dummy when developed to the same standard value of γ, usually unity. In the present case, in which the strips exposed through the different filters were on the same plate, they were necessarily given the same treatment, with consequent variation in γ. The ratio of exposures was, therefore, taken by extending the straight-line portions of the H. and D. curves until they intersected the log E axis, and reading the differences between these intercepts. We have noted in Chapter II that this intercept is constant for various treatments except for materials showing regression of inertia. Moreover, this effect is slight for the changes involved. Within this effect Table III gives true filter factors.

TABLE III

FILTER FACTORS

	Filter			
Subject	Aero No. 1	No. 12	No. 21	No. 25
Emulsion No. 2270				
Water	3.98	7.59	9.55	24.55
Woods	2.95	6.61	9.33	18.63
Hampton City	2.98	5.68	8.23	11.76
Light fields	2.41	4.46	6.47	12.60
Emulsion No. 1445				
Marsh	2.51	4.57	6.17	
Light fields	2.95	4.62	6.98	
Hampton City	4.02	6.77	9.55	

The interest in this table is in the change of factor with subject. The change with filter is largely a total transmission effect and is important in determining exposure times in practice with the particular filter and emulsion. It should be noted that the factors vary with the subjects in the same order as the values of γ. Water gives strikingly high values. The second emulsion confirms the order of light fields and the city of Hampton, and places the maximum of light from marshes farther toward the red. The marsh was covered

with dead red-brown foliage. The vegetation of woods and city was largely evergreen.

It is seen, therefore, that it would be unwise to apply to the whole problem the factors and γ values which were characteristic of the light from the white test object on the ground without first determining whether or not the H. and D. curve on the plates to be used suffered a measurable change as the altitude increased. To test this, it was necessary to expose through the tablet over a uniform subject large enough to insure no change in character of the light at higher altitudes. Two such subjects were accessible, the water of Chesapeake Bay and that of Hampton Roads. Many flights were made, and although a difference in the color of the two subjects was easily detected, no change with altitude was measurable. A typical flight over Hampton Roads gave the following data:

TABLE IV

Altitude	3,500	4,500	5,500	7,000	8,000	9,000	10,000	11,000	12,000 feet
γ	.89	.92	.88	.98	.86	.84	.88	.98	.93

On another flight exposures were made over both Hampton Roads and Chesapeake Bay. The values of γ show the same slight but irregular variation with altitude as those in the above table. They averaged for Hampton Roads 1.40, for Chesapeake Bay, 1.11. The difference in color of the two subjects was easily visible. These results made it possible to apply to all the images of the test objects made in a single flight, the curves obtained simultaneously on the ground by exposing through the tablet to light reflected from the same test object. Care was always taken in development. One or two plates with strips were treated in the same tray with three or four of the corresponding plates from the air, and marked accordingly, so that the interpretation of the negatives made in the aeroplane depended upon sensitometric strips of which the treatment had in all respects been the same. Whenever possible, plates exposed through a single filter were developed together, as this made it unnecessary to measure more than one strip of the five on the tablet.

METHODS OF MEASUREMENT

It is obvious, since the altitude of exposures varied from less than 500 to more than 12,000 feet, that the images on the plates must be of various sizes; indeed, they are squares measuring from 1 to 25 millimeters on each side. In the measurement of density, the large squares required only the

ordinary arrangement, with the plate to be measured placed under the opening of a Martens photometer. For the measurement of the smaller images, a projection apparatus was arranged as shown in Fig. 18. The end of the Martens photometer is covered by a paper diffusing screen, S_2, in front of which a black hood H is placed. The plate to be measured, P, is illuminated by light from the bulb B, through a watercell W,

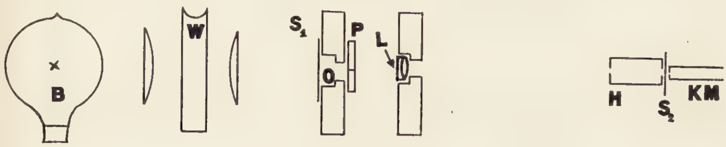

FIG. 18

Diagram of micro-photometer

and a diffusing screen S_1, and L is the projection lens. The emulsion is scraped from the plate up to a sharp line defining the image of the canvas, and an enlarged image of that part of the plate near the boundary is projected upon S_2 so that the clear glass covers one of the two openings of the photometer head, and the image covers the other.

The sensitometric strip corresponding to the negative was always measured in the same way as the images on the negative. Therefore, although the two methods did not measure precisely the same quantity, as the projection method gave a value for the density corresponding more nearly to that obtained by measurement by parallel light, there is little or no difference in the tabulated results of exposure ratios. In certain cases where it was possible to measure a plate in both ways, the two values of K obtained were in satisfactory agreement. Because of inequalities in the test objects, which produced inequalities in the density in some of the larger images, it was necessary to make several settings in different parts of the same square. This made the results comparable with those from the negatives made at higher altitudes, where the method naturally exerted an integrating effect. To determine the exposure ratio which in the formula for h was denoted as K, it was necessary to determine the photometer angle readings corresponding to the several sections of the sensitometric strip and to plot these angles against the log exposures —that is, a constant plus the log transmission of the tablet through which the strip was exposed. The constant involved

need not be known. The angles corresponding to the images of the canvas are then ascertained by the same method. By applying their values to the curve given by the strip, the appropriate difference in log exposure (which is the same as that between two values of log transmission) may at once be read. The antilog of this number is K, the ratio of exposures. It is usual in sensitometry to plot density rather than photometer angle as a function of log exposure, but here where the curves serve only as an intermediate means of interpretation, converting the angles to densities has no advantage.

REPRESENTATION OF RESULTS

The calculation of the photographic measurement of haze called h requires first a value for K at altitude zero, which has been denoted by C, the ground contrast. This represents the contrast presented by the test objects taken at 500 feet or less, where it was assumed that no haze was present. The value of C was found by plotting the values of K obtained from the data of any one flight as a function of h, thus getting the contrast-haze curve, and the most appropriate regular curve was extended to meet the axis of ordinates, where the intercept was the value of ground contrast C. It was observed that all the flights made could be divided into three distinct groups so arranged with respect to their dates and in relation to the weather conditions that the ground contrast C, which is the ratio of the brightness of the two canvases, remains unchanged for any one group of flights. The several values thus obtained for the flights of this group were weighted on the basis of the regularity or reliability of the corresponding curves and the "weighted mean" value used for C. In some cases, of course, the exposure of the plates was too great, and the density of the images of the white canvas was not represented by a corresponding density on the sensitometric curve of that plate. Under such circumstances, the curve gave a value for the ratio due to the black and the gray test objects, and this could be converted into K if multiplied by the ground contrast existing between the white and the gray test objects, which in turn could be obtained from another set of plates.

The calculation of h by means of the equation

$$h = \frac{C - K}{C\,(K - 1)}$$

gave the values which appear on the haze-altitude curves. The arrangement of the points allowed considerable latitude

as to the shape of curve best suited to represent the facts. Three general forms of curves, however, appear more or less adequate, and a straight-line, a logarithmic, and a parabolic curve were adjusted to the observations by a least-square solution. The parabolic curve represents a more uniform

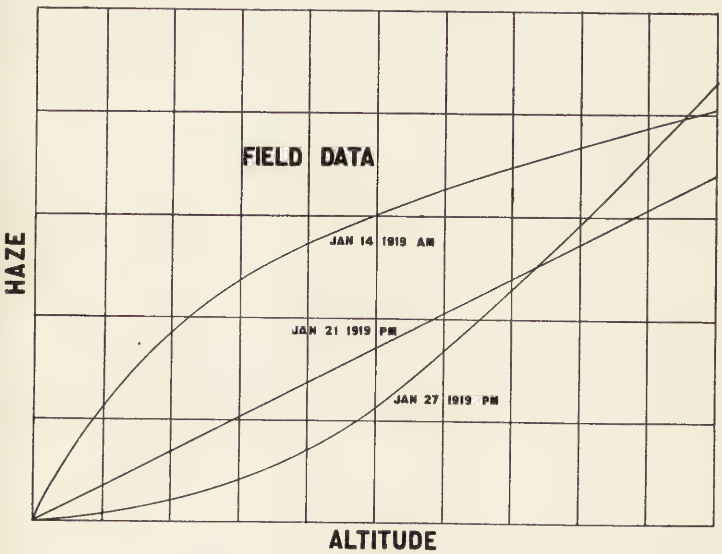

FIG. 19
Relation between haze and altitude

distribution of haze-forming material with altitude than the other type. The logarithmic type, being convex upward, represents a distribution in which the density of the haze diminishes with increasing altitude. The straight-line relation presents a case where haze is more or less proportional to altitude. These types of curves are shown in Fig. 19.

The variation of haze values with altitude under various weather conditions having been determined, the data with respect to the spectral quality of the haze remain to be interpreted. According to the terms of the definition of h, $E_w\ (1-a) + h'E_w$ is the exposure at any altitude. Of this amount, the first part $E_w\ (1-a)$ is the exposure due to the canvas as influenced by haze. The second part $h'\ E_w$ is the exposure due to the haze itself. The ratio of these two components is obviously $h'/(1-a)$, or h. It may be considered, then, that at a certain altitude the haze sends through a given

filter an amount of light which is a fraction h of the amount sent by the canvas through the haze and that filter. The canvas is assumed to be non-selective or neutral and, therefore, the light reflected from it has approximately the same spectral distribution as sunlight. The absorbing effect of the haze, however, is undoubtedly selective; and, therefore, $E_w\,(1-a)$ departs from the quality of sunlight.

It would be of interest to know at least the probable value of a, the absorption effect of haze. The ratio of $E_w\,(1-a) + h'\,E_w$ to E_w is the ratio of the two exposures at high and at zero altitudes respectively. That ratio is slightly greater than

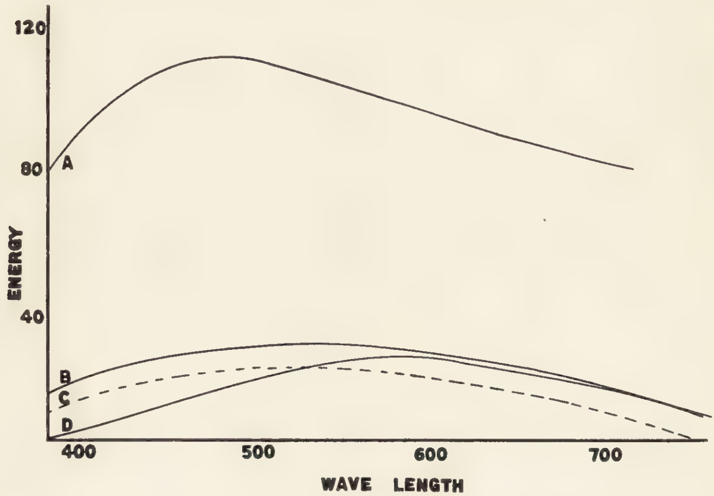

FIG. 20

A—Distribution of sunlight
B—Distribution of light from neutral canvas
C} Possible distribution of
D} light by haze

unity, and under conditions where the value of h equals 0.3, it is possible with a fair degree of accuracy to set $(1-a) + h'$ equal to 1.1. This value is undoubtedly less than 1.2. Taking $(1-a) + h'$ as 1.1 and $h'/(1-a)$ as 0.3, we get a = approximately 0.15 and h' approximately 0.25. If more data on the ratio of high and low exposures were at hand, it would probably be easy to separate these two values more definitely; nevertheless, it appears that $E_w(1-a)$ has a value of approximately 85 per cent of E_w. In the diagram in Fig. 20, A represents the distribution of sunlight, B that of the light

from the neutral canvas, and the curves C and D possible representations of $E_w(1-a)$, the areas under C and D being 15 per cent less than that under B. The data lead to the belief that the distribution indicated by curve D is more probable than that given by curve C.

As a first approximation and in order to exhaust the information available in the data, it is assumed that the light sent by the canvas through the haze is of the quality of sunlight. Then in any interval of the spectrum the illumination due to the canvas is proportional to the areas included between corresponding ordinates under the distribution curve of white light. The proportionality factor depends upon the reflecting power of the canvas. If this area be multiplied by a value of h derived from data obtained through a filter transmitting the spectral region concerned, the product represents, by the same proportion, the light from the haze. For two filters whose transmission bands are widely different, these two products

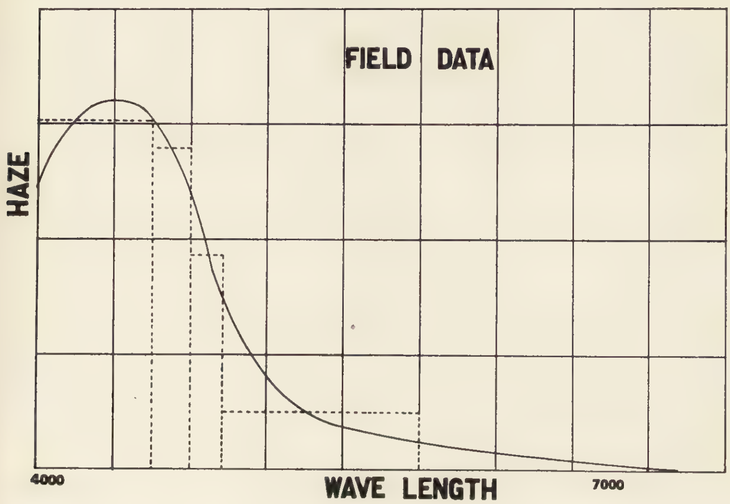

FIG. 21

will, in general, differ, since neither h nor the area multiplied are the same. Such a difference might be attributed to a haze effect in the region not common to the two filters. Therefore the difference of the products represents an area whose base on the wave-length axis is the spectral region transmitted by one filter and not by the other. The altitude is obviously the area divided by the base. These rectangles form the

basis of the h-wave-length curves (Fig. 21) which are so drawn that the areas under the curve and between the sides of any one of the rectangles are the same as that of the rectangle itself. In calculating these areas the values of h were taken from the haze-altitude curves for 10,000 feet. The transmission bands of the several filters extended variously from 2800 to 7000 Å. U. Evidently, the narrower and more numerous the rectangles in the spectral region involved, the more definitely the haze-wave-length curve may be determined.

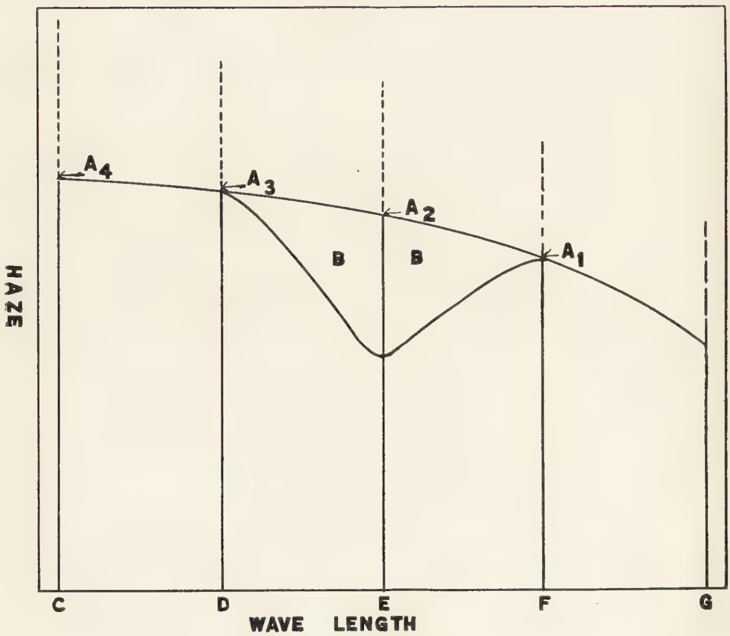

FIG. 22

It remains now to consider the nature of the change which would be produced in the color curves, were it possible to use the true distribution curves of the canvas exposures rather than those of daylight. In the first place, the correction to the curves probably falls where h is greatest, even though the haze value has been erroneously obtained. To take an extreme case, the curves given in Fig. 22 are to represent E_w and $E_w(1-a)$. In computing the first rectangle for the haze-wave-length curve, of which the base is EF, the expression used was area $= h_2a_2 - h_1a_1$, whereas what should have

been used was area $= h_2(a_2 - b) - h_1a_1$, which equals $h_2a_2 - h_1a_1 - h_2b$. Therefore, the area of the rectangle and its altitude should have been smaller. For the second rectangle, whose base is DE, the area was taken to be $h_3a_3 - h_2a_2$ instead of, as would have been correct, $h_3(a_3 - 2b) - h_2(a_2 - b)$, which is $h_3a_3 - h_2a_2 - 2h_3b + h_2b$. Both the rectangle and its altitudes were too large and should have been reduced. For the third rectangle, with base CD, the area used was $h_4a_4 - h_3a_3$, instead of the true value $h_4(a_4 - 2b) - h_3(a_3 - 2b)$; that is, $h_4a_4 - h_3a_3 - 2b(h_4 - h_3)$. This rectangle was a little too large, since in general h_4 is greater than h_3. The general effect is that, although all the ordinates of the haze-wave-length curves are too great, the maximum values should be reduced, but at the same wave-length. The conclusion is, therefore, that the light from the haze is more nearly white than it is represented to be by the haze-wave-length curves. Another determination which was not made for lack of time was the relative exposures at high and low altitudes from a single test object. With such information, it would be possible to separate the two components of h,—that is, h' and $1 - a$. Also, if this ratio could be obtained by light through various filters, the spectral quality of the exposure $E_w(1 - a)$, and hence the quality of light from the haze, could be obtained more definitely than has been possible. The observations necessary in order to secure these results would present no particular difficulty, although the two exposures could not be made upon the same plate.

CHAPTER IV

The Duplication of an Aerial Condition in the Laboratory

As already mentioned, haze so diminishes the contrast of the subject to be photographed that it is necessary to determine the photographic materials which should be used to produce the best results from subjects of extremely low contrast, as well as the best conditions for their use. For this purpose it was desirable that a constant and controllable haze condition should be established with which the material could be studied. There was therefore erected in the laboratory an apparatus by which an aerial condition could be simulated. This apparatus, termed the "haze cabinet," was a chamber approximately eight feet square, with walls and ceiling painted white. In it was placed a series of uniformly illuminated patches of different reflecting powers, similar to those used in the field work. The wall opposite the test objects held two batteries, each containing five 750-watt daylight tungsten bulbs which uniformly illuminated the test objects, and which were enclosed in a parabolic reflector. The aperture to the camera, which was also on this wall, was so protected as not to receive any direct light from the lamps. When the test objects were photographed a semi-transparent and reflecting mirror was placed between the lens of the camera and the objects. By means of this mirror a uniform veil of light could be superposed on the images of the patches to be photographed. The intensity of this veiling light could be controlled by means of a neutral-tinted gelatine wedge. In order that the cabinet might represent actual aerial conditions, it was calibrated in terms of haze as measured under conditions described above. The data obtained at Langley Field which established the quality and the quantity of haze present at various altitudes under various conditions, were utilized for this purpose. A gelatine screen was made for converting the light from the tungsten haze lamp to the color of the haze as determined for any particular flight. Then, from observations of the distribution and quantity of haze at various altitudes, the neutral tinted wedge was so calibrated that its settings duplicated the quantity of haze at any desired altitude. The exposure ratio at 500 feet (the ground contrast) was also established by means of the test objects in the cabinet, so that a given aerial condition was quite accurately reproduced.

In order to know the actual contrast of the subject in the cabinet and to determine how its range is disturbed by superimposing known amounts of haze, an intensity scale sensitometer similar to that used in the field work was printed in contact with the plate by light reflected from a large white screen of known selectivity in the cabinet. This screen was then raised, the image of the strip just exposed covered, and the test objects photographed.

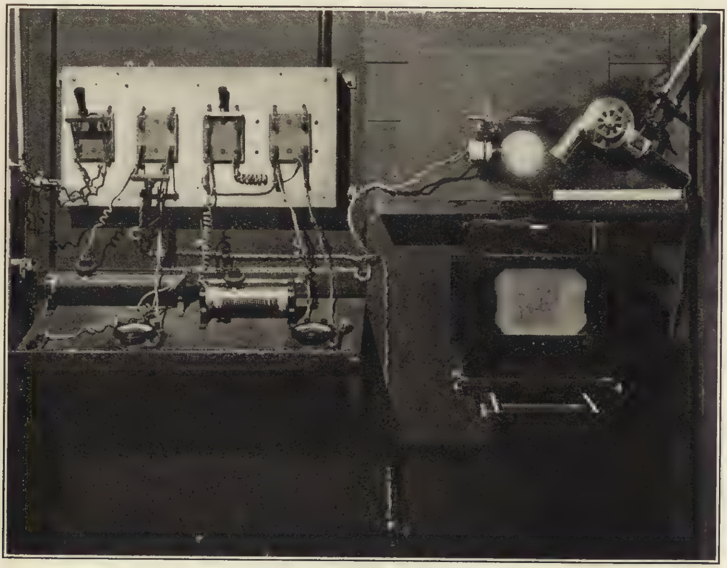

FIG. 23
Exterior of haze cabinet

Fig. 23 shows the exterior of the cabinet with the camera, the method of introducing the haze, and the control for both the interior cabinet lights and the haze lights. Control for both sets of lamps was effected by maintaining constant amperage.

Fig. 24 illustrates in detail the means of producing the haze. The light source is a 250-watt nitrogen-filled tungsten stereopticon lamp, above which is placed a parabolic reflector focusing the image of the filament on a piece of ground glass enclosed in a circular metal collar. An oblong case contains a neutral tinted wedge of dyed gelatine by which the intensity

of the light falling through the second piece of ground glass and thence on to the mirror is controlled. An electric blower

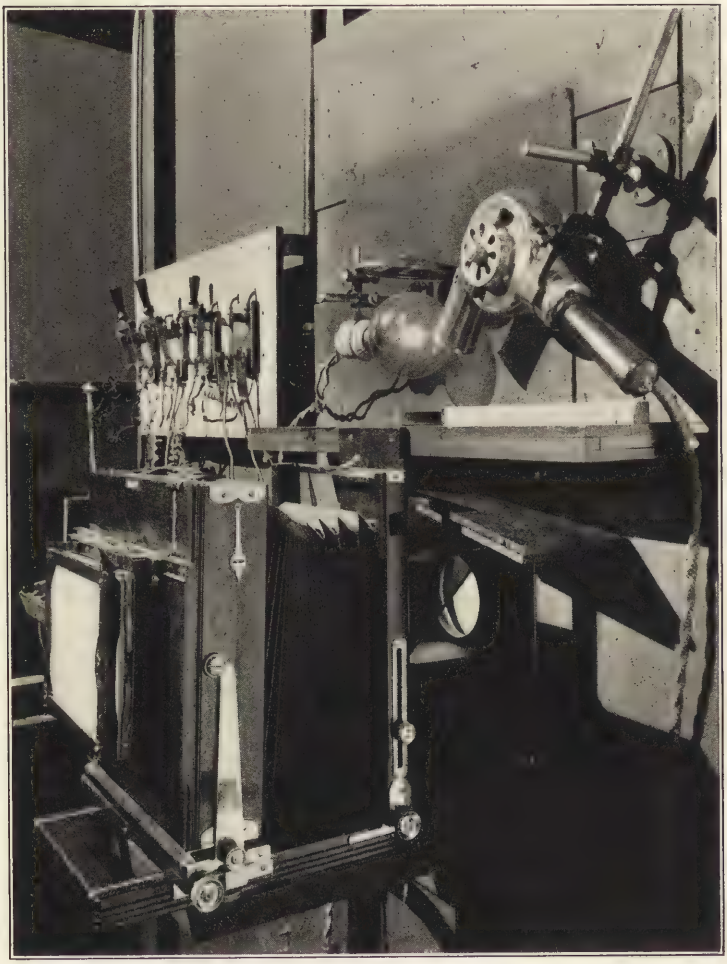

FIG. 24

Haze cabinet showing method of introducing haze

was used to keep the gelatine wedge cool. In order to obtain perfect and uniform diffusion over an area sufficiently large

for the purpose, the two diffusing media shown were necessary. The diffused light is reflected from a semi-transparent reflecting mirror through the lens and into the camera. The mirror was prepared by the cathodic deposition in vacuum of platinum iridium on glass, the coefficients of transmission and reflection being controlled by the depth of the metallic deposit. The light reflected from the test objects inside the cabinet passed through the aperture in the wall, then through the mirror placed at 45°, and thence into the camera. The test objects could therefore be photographed "unhazed," or any desired amount of haze could be introduced, the amount depending upon the setting of the wedge. The color of the haze was controlled by introducing a color filter over the second or lower opal glass.

The camera was fitted with a multiple back, in order to make nine exposures of the subject on the same plate. Thus photographs with various amounts of haze could be made on the same plate, which assured a minimum of photographic errors. The lens used was an Anastigmat ($f/7.7$), of a type similar to those used on the aerial cameras.

The illumination at the focal plane of the camera was first determined visually by an illuminometer. A white screen at the end of the cabinet reflected light through the platinized mirror and lens system and illuminated a magnesium carbonate block at the focal plane. A series of readings were taken with the illuminometer directed toward this block. A similar measurement was made using the haze light, again observing at the block in the focal plane, the camera being focused on the test objects in the cabinet. The wedge was set at zero, in which position it transmits completely. However, the illumination was too faint for settings of great accuracy, and the data thus acquired are probably not so reliable as those obtained by the photographic method.

The necessary calibration of the wedge was obtained visually from readings of the light incident on the platinized mirror with the camera lens removed. The factor to be applied to reduce this to its value at the focal plane was found from readings taken for the zero position of the wedge. The wedge proved to have densities very nearly proportional to the distance from one end—that is, the logarithms of the transmitted illumination varied directly as the wedge settings. At the focal plane, the haze illumination varied between .4356 and .00213 meter-candles. At the position of the plate used in exposing through the tablets, however, this was reduced, for the zero wedge settings, from .4356 to .2240 meter candles.

The illumination from the white screen in the cabinet was almost exactly one-third of that received from the haze light through the wedge in zero position at the same plane. The haze light could therefore be changed continuously from zero to a value three times that of the brightest part of the subject.

As stated above, the test objects used in the cabinet were miniature duplications of the canvases used in the field. For these, six sheets of smooth-finished photographic paper were exposed for increasing lengths of time and developed in a developer which insured neutral results. The reflecting powers of these test objects were measured visually with the Nutting absolute reflectometer. Though this instrument does not duplicate exactly the lighting conditions in the cabinet, the results obtained give with sufficient accuracy the visual contrast of the subjects, as follows:

Subject No.	1	2	3	4	5	6
Reflecting Power	78.06	67.34	42.62	18.61	13.74	10.40 per cent.

Thus the extreme contrast between the subjects is about eight to one, with sufficient gradations between to allow a study of intermediate exposures.

The haze lamp of the cabinet was screened to a bluish color to duplicate the color of haze on one particular flight. The wedge was calibrated in terms of altitude or of haze values at various altitudes on the same flight. The neutrality of the wedge was then determined by noting any change in γ on plates exposed at intervals throughout the total range of the wedge. This was done on ordinary, ortho, and panchromatic plates, and no change in γ, indicating a change of quality of the light transmitted by the various sections of the wedge, could be noted. Thus the cabinet duplicated a given flight under conditions which could be maintained and controlled. The photographic results were then related to the H. and D. curves in such a way that the advantages or disadvantages of various materials and treatments could be analyzed.

The importance of obtaining the sensitometric data under precisely the conditions of the exposure studied has already been emphasized. To ensure this, tablets were made which would allow a strip to be exposed on each end of the plate used for photographing the test objects. The strips used for the intensity scale sensitometry, which were prepared in the same way as those used in the field work, were found to be photographically neutral. One of the strips was exposed directly to the haze glare when the cabinet lights were extinguished.

In making the other strip, for which the cabinet lights only were used, the light was reflected from the white curtain

which could be lowered in front of the test objects, and which completely filled the field. To ensure uniform lighting of the tablets, the plate was placed about ten centimeters behind the focal plane. The strips were made on the same plate as the images of the test objects, and the use of two strips made it possible to compare the quality of haze and the cabinet lights. By means of the multiple back, it was possible to make nine exposures on each plate, thus obtaining a complete range of haze intensities.

After development and subsequent fixation and drying of the plates exposed as described above, the densities obtained were read and referred to the curve plotted from the relation between the densities obtained from the tablet and the exposures which produced them, thus enabling a determination of the range of the subject photographed to be made. This was done with various amounts of haze superimposed.

Thus it was possible to study the way in which haze reduces contrast and how various photographic materials behave under identical haze conditions. The data obtained were plotted in curves showing the relation between the contrast of subject and the haze over the range obtainable under cabinet conditions, and the relative behavior of the various types of photographic materials. At the same time, data were obtained as to the exposure and development for securing the best results under haze conditions.

The sensitometric characteristics of the plates best suited for air work were studied and methods of interpretation devised by which suitable sensitometric methods and data would give all possible information concerning the usefulness of a plate for photography in the air.

The effect to be studied may be called "contrast," but the word must not be understood to be used in the sense in which it was used in the section on sensitometry. There contrast signified the rate of change of density with the logarithm of exposure, and depended solely on the plate used and its development. Here it is desirable to classify the plates as records rather than as related to the exposures to which they were subjected. Thus we can measure the contrast as the difference in the densities produced for a given pair of subjects or, more conveniently, as the ratio of the opacities, the value of which the density difference is the logarithm. The most suitable plate for aerial photography will give the greatest opacity ratio for a given pair of subjects under the most unfavorable conditions of haze and under exposure.

When both the subjects lie on the straight-line portion of the H. and D. curve it is quite easy to predict the effect that haze glare will have on the opacity ratio, especially when the haze and the subject are of the same color. Let E_1 represent the exposure due to the first subject, E_2 that due to the second, and e the exposure due to haze, to be added to both E_1 and E_2. The equation for the straight-line portion of the H. and D. curve may be written.

$$D \log O = \gamma (\log E - \log i);$$

and for the two subjects, therefore

$$\log O_1 = \gamma (\log [E_1 + e] - \log i)$$

$$\log O_2 = \gamma (\log [E_2 + e] - \log i).$$

Subtracting,

$$\log (O_1/O_2) = \gamma \log \frac{E_1 + e}{E_2 + e};$$

denoting O_1/O_2 by C,

$$C = \left(\frac{E_1 + e}{E_2 + e}\right)^{\gamma},$$

which may be written $(C^{\frac{1}{\gamma}} - 1)(E_2 + e) = E_1 - E_2$

In the case where γ is unity, this is the equation of a rectangular hyperbola between C and e with the asymptotes $C = 1$, $e = -E_2$. It intersects the axis $e = 0$ at $C = E_1/E_2$, the true exposure ratio. As γ increases, all values of C increase, and the curve does not cling to its asymptote $C = 1$ so soon. Lower γ's decrease all values of C.

It is clear that if one could be sure of obtaining all exposures on the straight-line portion of the curve, the problem would consist only in obtaining the highest possible value of γ. But exposures from the air are frequently so short that the densities are apt to lie on the toe of the curve. Aside from under-exposure, the question of latitude is a vital one, especially for high values of γ, where it is not only reduced but also complicated by fog at the low densities.

The effect of γ on opacity ratio in practice is shown in the curves in Fig. 25. The different curves correspond to settings of the neutral wedge, that is, to different amounts of haze glare. According to the equation above, these curves should be logarithmic. They have this general shape, although somewhat distorted by toe and shoulder effects and unequally

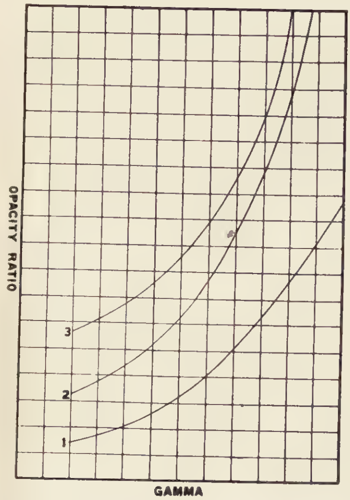

FIG. 25
Variations of contrast with γ for various amounts of haze

so because corresponding ordinates are not necessarily given by equivalent exposure times.

Fig. 26 shows another set of curves obtained with a Seed 23 plate. The abscissae here are haze brightnesses. We see the hyperbolic type predicted from the equation for these coördinates. Each curve corresponds to a given γ and a fixed exposure time. The group of similar flat-lying curves, marked A, which are displaced upward with increasing γ, were obtained with an exposure which kept the subject as near as possible in an equivalent position on the corresponding H. and D. curve. The curves marked B were given by longer exposures,

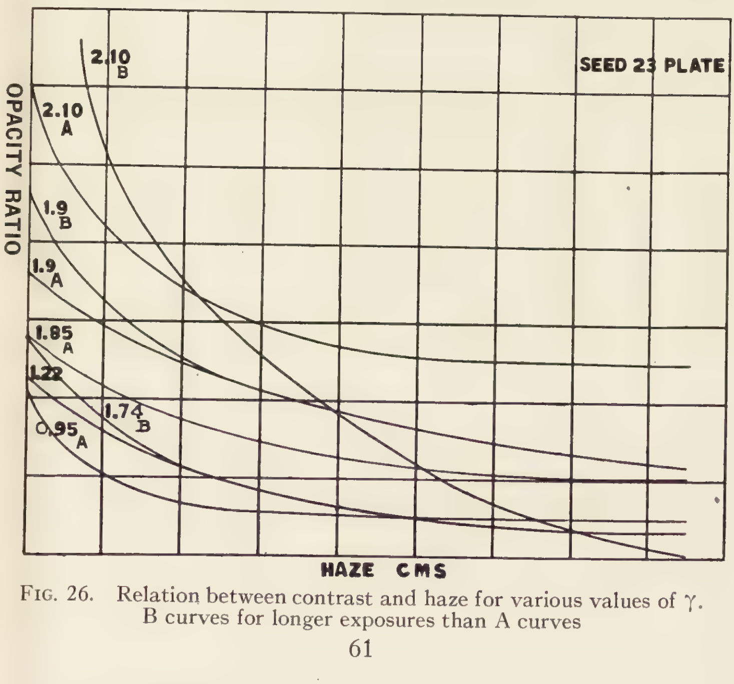

FIG. 26. Relation between contrast and haze for various values of γ. B curves for longer exposures than A curves

which reduce the toe effect on low haze values and increase the shoulder effect on high haze values. This illustrates how important the shape of the toe may be when latitude has been exceeded, or when the exposure is shorter than that usually required by the plate. One may see also in these curves a fact which was still more obvious in Fig. 25, viz., that as γ increases, the opacity ratio becomes increasingly sensitive to slight variation of γ and consequently of the time of development.

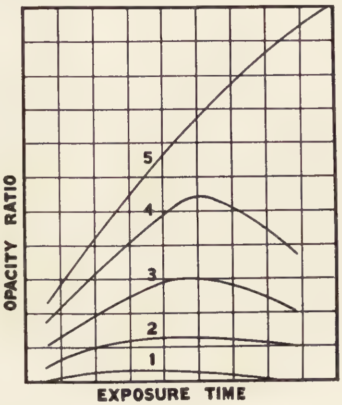

Fig. 27
Relation between contrast and exposure time for differing amounts of haze

The question of exposure time is further dealt with in Fig. 27. Here the abscissae are exposure times and the various curves are drawn for different amounts of haze. The maximum of the curve in each case indicates the exposure best suited to give high contrast for the pair of subjects in question. The increasing intensity of light (subject + increasing haze), naturally shifts this maximum to the right for decreasing haze. These curves were obtained from Seed 23 plates and for high γ's. It is interesting to note how steep these curves may be for slight haze, and how marked their maximum.

Fig. 28 shows a group of curves similar to those in Fig. 26, but selected so that the exposure falls as nearly as possible at its optimum. Such a series of curves represents an emulsion at its best. In practice, exposures could not be estimated so accurately. The photographer is therefore interested in knowing how rapidly the contrast diminishes with a change of exposure.

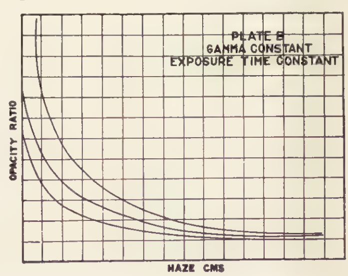

Fig. 28
Relation between contrast and haze for various gammas

(In Fig. 29 an endeavor has been made to assemble optimum curves of the type of Fig. 28 for a group of emulsions. These curves unfortunately contain no information as to speed, which is doubtless very necessary. They give, however,

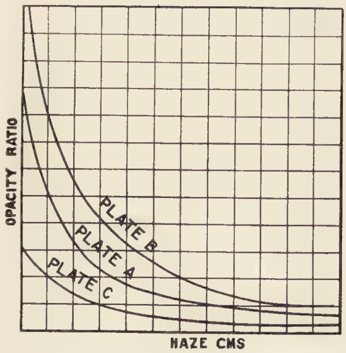

FIG. 29

Relation between contrast and haze for various emulsions

the relative value of the emulsions for aerial work at each haze value, assuming that the maximum exposure is sufficiently high to allow each plate its optimum exposure. If the plate were too slow for that it would be necessary to substitute for its curve one obtained at the best exposure possible.)

Thus it is seen that, from measurements made with the haze cabinet, the relation between haze and the contrast obtained in the photograph can be determined, as well as the conditions under which the effect of haze is minimized and the best contrast is obtained. In the next chapter, the practical applications of the results obtained, as well as the use of color filters to increase the contrast in aerial photography, will be discussed.

CHAPTER V

The Materials and Conditions Best adapted for Aerial Photography

Photographic emulsions are classified by means of the constants which control their characteristic curves. In Fig. 30 are shown the curves of two materials differing in speed and in contrast, development having been carried to the limit, so that the contrast is represented by the maximum slope of the line obtained. One of the emulsions shown would be classified as a fast emulsion of moderate contrast, γ_∞ being 1.6, and the other as a slow emulsion of great contrast, γ_∞ being approximately 2.6.

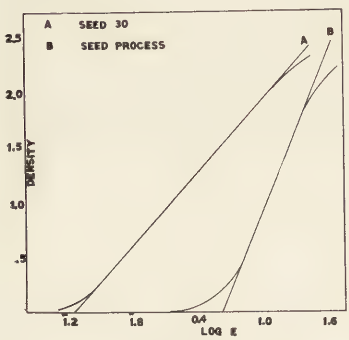

FIG. 30

A—Fast emulsion of moderate contrast

B—Slow emulsion of great contrast

Since in aerial photography the materials are very often under-exposed, their relative speeds can not be compared in the correct exposure region, as is done according to the conditions laid down by Hurter and Driffield. Instead, the relative exposures required to produce sufficient printing density throughout the region of under-exposure are compared, since, as has been stated, in practical aerial photography the region of under-exposure is generally of greater importance than that of correct exposure. The characteristics of the under-exposure portion of the curve are best shown not by plotting the density against the logarithmic exposure, but by the derivative of this curve; that is to say, the slope of the characteristic curve is plotted against the logarithmic exposure, $dD/d \log E$ against $\log E$. This is shown in Fig. 31. The gamma of the characteristic curve is now shown as the maximum height of the derivative curve, the straight-line portion of the characteristic curve being represented by the portion of the derivative curve which is horizontal and parallel to the X axis, and the sloping portions of the derivative curve corresponding respectively to the under- and over-exposure portions of the characteristic curve.

When the derivative curves are plotted for the same emulsion for different times of development, the series of horizontal lines obtained correspond to the different γ values of the characteristic curves, and if no regression of the inertia occurs, the point at which the line becomes horizontal remains fixed

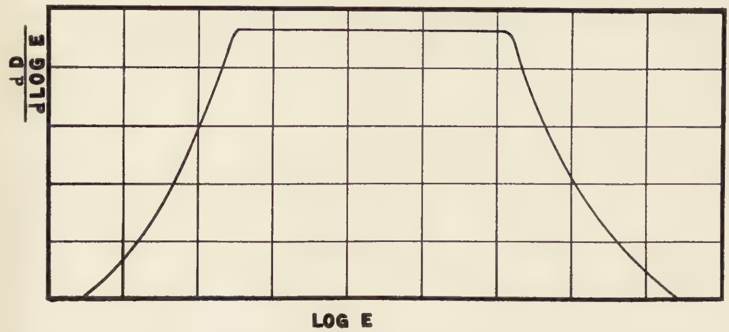

Fig. 31
Relation between slope of characteristic curve and exposure

with regard to the exposure axis as development is continued; that is, a line passing through the junction points of the under and correct exposure regions for the different kinds of development will be vertical, as is shown in Fig. 32. In practice, how-

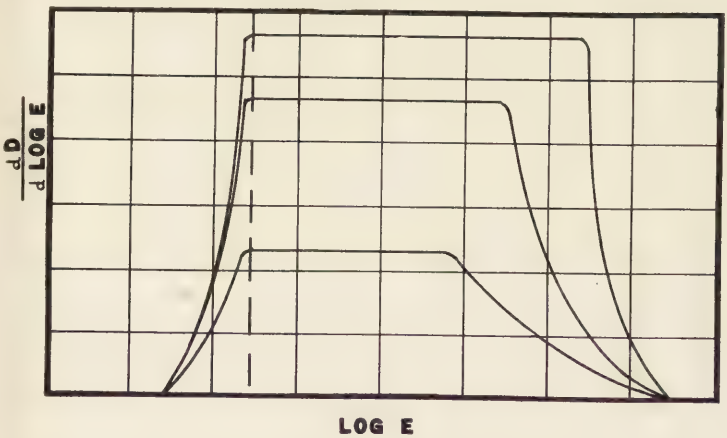

Fig. 32
Derivative curves for various gammas on same emulsion without regression of inertia

ever, there is usually regression of the inertia, and the line passing through the junction point is no longer vertical, the influence of the regression being shown by a shift of the point as development is continued (Fig. 33). Fig. 34 shows a typical case of this, the plate being the Stanley Commercial. Increased development has caused a considerable regression of the inertia, the horizontal portion of the curve (corresponding to the straight-line portion of the H. and D. curve beginning at lower exposure for the upper curve. Fig. 35 shows the behavior of a group of emulsions with regard to the underexposed region, these being drawn for the best values of γ.

From the work in the haze cabinet it is clear that the plate which produces the greatest opacity ratio for a given contrast of subject under the most unfavorable haze conditions is most suitable for aerial photography. The materials selected, therefore, will be of high contrast and consequently of somewhat low sensitiveness, and the regression of the inertia will make it possible to use materials of higher contrast than would

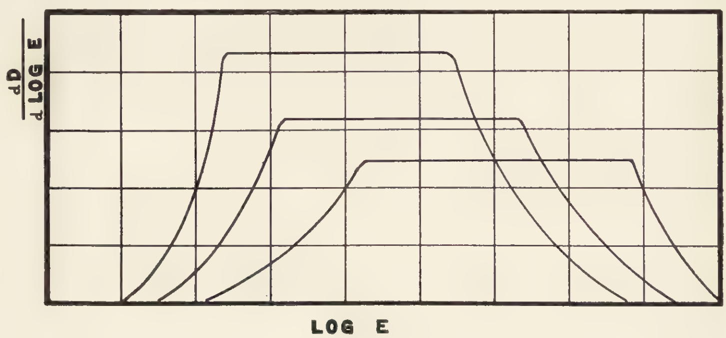

FIG. 33

Derivative curves for various gammas showing regression of inertia

otherwise be practicable, owing to the limitation imposed by considerations of exposure. No material is suitable for use in aerial photography the γ_∞ or limiting contrast of which is lower than 2, while the practical conditions of exposure show very clearly that the speed under the conditions of maximum development must not be lower than 100 H. and D. in order to allow for the use of the necessary color filter. The question of exposure requires special consideration.

The longest exposure which can conveniently be given in an aeroplane is about 1/50 of a second, but under ordinary working conditions it is more practical to assume that the longest

exposure should not be more than 1/100 of a second because of the effect of vibration. Therefore, 1/100 of a second may be selected as the standard convenient exposure for airplane photography. This assumes, of course, the use of an airplane having the least vibration, and of the most suitable camera and suspension, and the placing of the camera and suspension in the best part of the aeroplane.

It can be shown[1] that the effective speed of the emulsion is related to the exposure and to the intensity of the light reflected from the subject by the equation

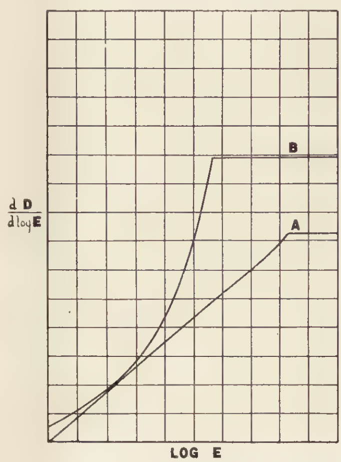

FIG. 34

Relation between slope of characteristic curve and exposure for two gammas

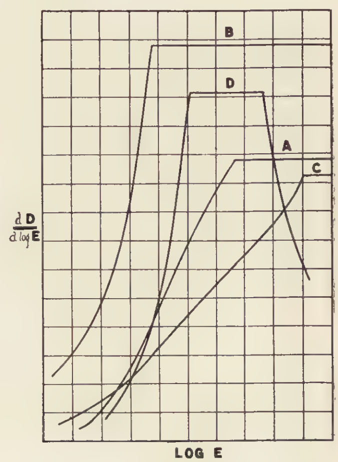

FIG. 35

Relation between slope of characteristic curve and exposure for various emulsions

$$P = \frac{500}{L\ E},$$

where E is given in seconds and L in foot-candles of brightness. This equation applies to a lens of aperture $f/8$. If, instead of a lens of aperture $f/8$, we use a lens of aperture $f/4.5$, the equation becomes

$$P = \frac{500}{3L\ E}.$$

Filling in 1/100 for E, we have

$$P = \frac{50{,}000}{3\ L}.$$

[1] Mees, C. E. K., Fundamentals of Photography, p. 55. (Eastman Kodak Company, Rochester, New York).

For a sunlit landscape from the air, L will have a value as high as 1000 foot-candles, and under these conditions $P = \frac{50{,}000}{3{,}000}$, or approximately 17.

For aerial photography in bright sunlight, therefore, materials having a working speed (with a filter), of approximately 17 can be effectively used. For the most red sensitive plates available, the factor of the red filter has been reduced to 6.[1] Under the best aerial conditions, therefore, it would be possible to use such plates with a red filter, even if their H. and D. speeds did not exceed 100. It is, of course, quite possible to obtain materials of this speed having the requisite contrast.

It will be seen that the red filters can be used only under the very best conditions, when strong sunlight is falling upon the subject to be photographed. Under other conditions, lighter filters are necessary. When, instead of panchromatic materials, those sensitive to the yellow-green only are used, the very best materials examined were found to have with the No. 12 strong yellow filter an effective speed of 25. These would make possible exposures from the air under conditions approximately half as favorable as the best conditions which occur, even with this strong yellow filter. The following table of various materials and their effective speeds through different filters is useful in this connection:

Material	Speed with no filter	Effective Speed through Filters K-1	K-2	Aero 1	Aero 2	No. 12	No. 25
Process Panchromatic or M	60	40	20	30	25	10	5
Panchromatic Plates (Ordinary)	120	80	40	60	50	20	10
Panchromatic Plates (Extreme red sensitive)	200	150	70	120	80	50	30
Panchromatic Aero Film	120	60	30	45	35	15	7
Panchromatic Aero Film (Hypersensitized)	200	150	70	120	80	50	30
Orthochromatic Plates (Ordinary)	200	60	20	40	30	8	..
Orthochromatic Plates (Extreme green sensitive)	200	100	50	70	50	25	..
Aero Ortho Film	150	50	15	30	25	8	..
Seed 30 Plates	400	150	20	50	30	5	..

[1] See Chapter II.

The curves shown in Figs. 21 and 22 (pp. 51 and 52), giving the distribution of haze at different wave-lengths, make clear the great importance of the use of color filters restricting the exposure as much as possible to the longer wave-lengths. The haze is predominantly blue with a decided maximum at 450 $\mu\mu$. It is obvious, therefore, that a sharp cut yellow filter is of the greatest advantage in removing the greater part of the haze, but that the longer the average wave-length which can be used, the greater will be the penetration obtained.

A considerable number of filters were used experimentally in the work. The conclusion reached by the Army fliers was that there is no advantage in using a filter lighter than the K-1½, but this was before the new filters made with Eastman Yellow were introduced. When these were used, it was found that the

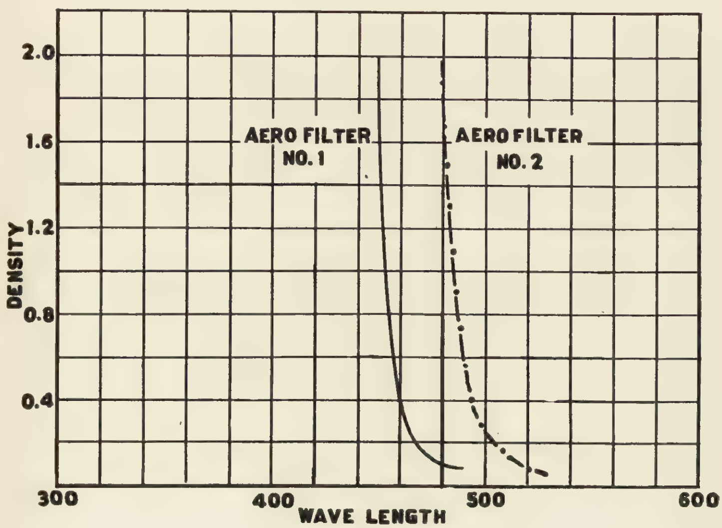

Fig. 36

Aero No. 1 filter, which is a little lighter than the K-1½, gives a very decided increase in the effective contrast. The filters finally adopted were Aero No. 1, K-1½, Aero No. 2, K-2, No. 12, No. 15, No. 21, and No. 25. The absorption curves of filters Aero No. 1 and Aero No. 2 are shown in Fig. 36. K-1½ and K-2 may be eliminated, as they are certainly inferior to Aero No. 1 and Aero No. 2. No. 15 and No. 21 may also be excluded, which leaves a set of four filters best suited

for aerial photography: Aero No. 1, Aero No. 2, No. 12, and No. 25. The choice between these is determined by the exposure conditions available. For ordinary panchromatic plates the exposure factors are as follows:

Filter	Panchromatic Plates	Extreme Red Sensitive Panchromatic Plates	Panchromatic Film	Hypersensitized Panchromatic Film	Aero Ortho Film and Orthochromatic Plates	Extreme Sensitive Orthochromatic Plates
Aero No. 1	2	1½	2½	1½	5	3
Aero No. 2	3	2½	4	2½	6	4
No. 12	6	4	8	4	20	8
No. 25	12	6	14	6	..	.

Obviously, the strongest filters, Nos. 12 and 25, can be used only with the most sensitive panchromatic materials. They can be used with Wratten panchromatic plates under the best conditions of lighting, and No. 12 can be used with panchromatic film under similar conditions. When the lighting is in any way inferior, and generally when it is necessary to use No. 25, hypersensitized materials are necessary. The filter known as Aero No. 2 can be used only under good conditions of lighting and with strongly orthochromatic film or plates. For such materials, with lower color sensitiveness, Aero No. 1 is the standard filter.

The conditions of development used should be those producing the lowest possible inertia and at the same time the highest possible contrast in the resulting negative. In practice, this involves the use of developers containing a large amount of restrainer, which produce high contrast without fog, and at the same time having high reduction potential, which favors the production of negatives corresponding to the lowest possible inertia in the emulsion or, in other words, gives the maximum detail in the shadows. After a careful sensitometric study of a number of developing formulae a formula was selected as giving the best practical results; but there are two objections to the use of this developer—(1) it proved very expensive, and (2) it contained chlorhydroquinone, the supplies of which during the war were limited, and which is not always conveniently available. The Aerial Service therefore substituted the following formula, and though this does not give quite as low an inertia as the metol-chlorhydroquinone formula originally selected, it is very similar, and is quite satisfactory:

Metol	16 grams;
Hydroquinone	16 grams;
Sodium sulphite	60 grams;
Sodium hydroxide	10 grams;
Potassium bromide	10 grams;
Water to	1 liter.

Sensitometric comparison of this developing formula with the pyro or pyro-metol formula previously used, shows that the former requires appreciably less exposure and that it gives a somewhat higher contrast than could be obtained by the latter.

APPENDIX

The Haze Effect Produced by Pure Dry Air

Although the mass of air below a certain altitude changes with the temperature and pressure, this mass is much more nearly constant than are the amounts of the other constituents of haze. Also, the distribution of the air, or its change of density with altitude, is, for isothermal conditions, definitely known. The actual transmission of light by dry air, as a function of wave-length, is given in a paper by Fowle.[1] This makes it possible to estimate the amount of haze due to air alone. The methods of the calculation apply as well to the effects of water vapor, but as we do not know the mass involved, its distribution, or the transparency of the material, we can not get a numerical result for the amount of haze which it causes. To go back to these quantities from observational data may become possible, but will require the accumulation of much additional material.

The magnitude of the dry air effect may be estimated as follows: Assuming a uniform temperature and composition, if d_0 is the density of the air at the altitude $a = 0$, the density d, at altitude a is

$$d = d_0 e^{\frac{-gma}{RT}}$$

where e, g, m, R, and T are respectively the base of the natural log system, the acceleration due to gravity, the "molecular weight," 29, of air, the gas constant, and the absolute temperature. Evidently g depends upon a, but in so small a measure, for the altitude concerned, that it may be regarded as constant. Taking $T = 283$ we have

$$d = d_0 e^{-ba}$$

and $$b = 121 \cdot 10^{-8}$$ in c. g. s. units.

Consider now a very thin layer of the diffusing medium with parallel radiation incident upon it. This radiation is weakened by scattering and absorption. The decrease in intensity di, where i is the incident light (measured in ergs per cm.[2] per second), is proportional to the original intensity i, to da the thickness, and to d, the density. Thus,

[1] Fowle, The Atmospheric Scattering of Light, Smithsonian miscellaneous collections, Vol. 69, No. 3. 1918.

$$di = -c'id \cdot da;$$

di represents a decrease in *i*, and, if *da* is an increase in *a*, the minus sign should be used. Of this loss *di*, the part scattered is, say, $c'id \cdot da$. It is assumed that the light is scattered equally in all directions. Now the receiving surface or the open area of the lens is to be at a height *S*, the medium will extend further up to altitude *t*, and the diffusing layer in question is at a height *a*, below *S*. Of this whole layer, the extent of which is very great, a limited area *A*, determined by the solid angle of the lens, sends light towards the receiving surface. If this solid angle is β and *d* is the distance from *S* to *a*,

$$\beta = A/d^2$$

Now, from unit area of the layer, corresponding to a volume *da*, the scattered radiation is:

$$c'\, i_a d_o \cdot e^{-ba}\, da,$$

and of this the fraction $\frac{L}{4\pi d^2}$, where *L* is the effective area of the stop, will start toward the lens. Since *A* is small compared to d^2, the effective radiation *dr* from the whole layer is

$$dr = \frac{c'\, L\, \beta\, d_o}{4\pi} A_a e^{-ba}\, da.$$

Of this, however, not all strikes the lens, as it is subject to the scattering between its own level *a*, and that of the lens, *S*. Here, for the loss in any layer, since the radiation is directed upward,

$$di = -c i_a\, d_o e^{-ba}\, da$$

Whence, integrating from *a* to *s*,

$$\log i_s - \log i_a = \frac{cd_o}{b}\left(e^{-bs} - e^{-ba}\right)$$

$$\text{or} \qquad i_s = i_a\, e^{\frac{cd_o}{b}\left(e^{-bs} - e^{-ba}\right)}$$

Therefore, from the layer at altitude *a* there actually reaches the surface of the lens the radiation

$$dr = \frac{c\, L\, \beta\, d_o}{4\pi} A_a\, e^{-ba}\, e^{\frac{cd_o}{b}\left(e^{-bs} - e^{-ba}\right)}\, da.$$

If i_t is the radiation at a height *t*, above *S* and *a*, it will be subject, in going down to *a*, to the same sort of diminution, so that

$$i_a = i_t\, e^{\frac{cd_o}{b}\left(e^{-bt} - e^{-ba}\right)}.$$

Finally,

$$dr = \frac{c' L \beta d_o}{4\pi} i_t e^{-ba} e^{\frac{cd_o}{b}(e^{-bs} + e^{-bt} - 2e^{-ba})} da$$

$$= \frac{c' L \beta d_o}{4\pi} i_t e^{\frac{cd_o}{b}(e^{-bs} + e^{-bt})} e^{-ba} e^{-\frac{2cd_o}{b}} da,$$

which can be written (combining symbols into J and v)

$$dr = J e^{-ba} e^{ve^{-ba}} da.$$

Since $\qquad d(e^{-ba}) = -be^{-ba} da, \qquad$ we can write

$$dr = -\frac{J}{b} e^{-ba} e^{ve^{-ba}} \frac{d(e^{-ba})}{e^{-ba}} = -\frac{J}{b} e^{vx} dx.$$

If $x = e^{-ba}$, the total radiation from the haze is evidently

$$R' = \int_{a=o}^{a=s} dr = -\frac{J}{b} \int_{1}^{e^{-bs}} e^{vx} dx$$

or ultimately,

$$R' = \frac{c' L \beta}{8 \pi c} i e^{\frac{cd_o}{b}(e^{-bs} + e^{-bt})} \left\{ e^{-2\frac{cd_o}{b} e^{-bs}} - e^{-2\frac{cd_o}{b}} \right\}.$$

This is the light from the haze reaching the lens within its whole solid angle. Let the transmission of the lens be represented by the factor M, and let f be the focal length of the lens, so that $1/f^2$ will be the solid angle corresponding to unit area of the plate exposed; then, multiplying R' by M and by $1/f^2$, and dividing by β, we shall have for the exposure on the plate in ergs per cm.^{2} per second:

$$R = \frac{C' L M i_t}{8 \pi f^2 c} \left\{ e^{\frac{cd_o}{b}(e^{-bt} - e^{-bs})} - e^{\frac{cd_o}{b}(e^{-bt} + e^{-bs})} \right\}.$$

This is an expression for the "luminous veil effect" of the haze.

Evidently, if $s = 0$, we have $R = 0$. Also, ($d_a = d_o e^{-ba}$ being the expression for the density of the medium), if $b = 0$, we have $d_a = d_o$, or the density is uniform. If this be the case,

$$R = \frac{c'LMi_t}{8\pi f^2 c}\left(e^{-cd_o(t-s)} - e^{-cd_o(t+s)} \right),$$

an expression which was obtained independently, thus checking the preceding formula for R.

The subtractive effect of the haze may be considered as follows: As has been stated, the illumination of the test objects (in ergs per cm.[2] per second) is

$$i_o = i_t \, e^{\frac{cd_o}{b}\left(e^{-bt} - 1\right)}$$

since $a = 0$. Let p represent the reflective power of the test object, the fraction of normal incident radiation scattered, per unit solid angle, in a vertical direction by the white canvas. Each square centimeter of this area sends toward the lens

$p i_t \, e^{\frac{cd_o}{b}\left(e^{-bt} - 1\right)} \frac{L}{s^2}$ ergs per second. This is subjected to the diffusing action of the haze in the region below s. As on page 73, where, for radiation directed upward,

$$i_s = i_a e^{\frac{cd_o}{b}\left(e^{-bs} - e^{-ba}\right)}.$$

the radiation incident upon the lens is, since $a = 0$,

$$\frac{Lpi}{s^2} + e^{\frac{cd}{b}\left(e^{-bt} - 1\right)} e^{\frac{cd_o}{b}\left(e^{-bs} - 1\right)}.$$

This is partially transmitted by the lens, and falls upon an area f^2/s^2 of the plate. Therefore, the exposure in ergs per cm.[2] per second is

$$E'_w = \frac{Lpi_tM}{f^2} e^{\frac{cd_o}{b}\left(e^{-bt} + e^{-bs} + 2\right)}.$$

If $s = 0$,

$$E_w = \frac{Lpi_tM}{f^2} e^{\frac{cd_o}{b}\left(e^{-bt} - 1\right)}.$$

This quantity was used in the definition of haze. Also, if $b = 0$ the medium is uniform and

$$E_1 = \frac{Lpi_tM}{f^2} e^{-cd_o(t+s)}.$$

It is possible now to obtain an expression for haze, since

$E'_w = (1 - d)\, E_w$, and therefore $1 - d = exp\left(\frac{cd_o}{b}\left(e^{-bs} - 1\right)\right)$.

Also, $h' E_w = R$. Hence,

$$h' = \frac{c'}{8\pi pc}\left(exp\left[\frac{cd_o}{b} (1 - e^{-bs}) \right] - exp\left[\frac{cd_o}{b} (e^{-b-s} - 1) \right] \right).$$

Therefore, since $h = \dfrac{h'}{1-d}$,

$$h = \frac{c'}{8\pi pc}\left(e^{\frac{?cd_o}{b}} (1 - e^{-bs} - 1 \right).$$

This is the desired expression for the haze effect of dry air, or for any medium whose density changes with altitude according to the same law. As a special case in which $b = 0$, it gives the effect for a uniform distribution. To obtain actual values for h, however, it is obviously necessary to have values for the constants involved, namely c', cp, d_o, and b. It is possible to find these for dry air, as follows:

In the first place, c' refers to the scattering effect of the medium, and c to the total decrease in the passing light. They are not equal if there is any absorption. But, according to the work of Strutt,[1] we may take the absorption to be very small, and $\frac{c'}{c}$ may be put equal to 1 in the coefficient of the h formula. The evaluation of p, which, it will be remembered, is the fraction of normal radiation scattered vertically per unit solid angle, is at least approximately possible. From measurements made upon the white canvas, it appears to scatter throughout the hemisphere 0.6 of the radiation incident perpendicularly, and in this nearly to follow Lambert's law. In a vertical direction the radiation is i_p per unit solid angle, and therefore in the small solid angle $d\omega$ it is $i_p\, d\omega$. In any other direction determined by α, as in the figure (Fig. 37), the intensity is $i_p\, d\, \omega \cos \alpha$. Since i depends on α only, we can select an elementary solid angle $d\omega$ corresponding to an infinitesimal zone contained between α and $\alpha + d\alpha$; that is to say,

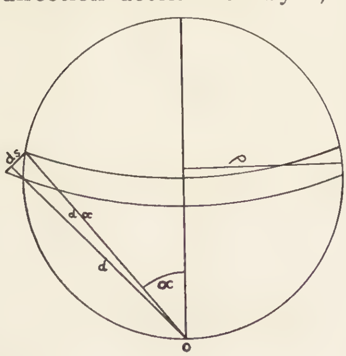

FIG. 37

$$d\omega = 2\pi \sin \alpha \,.\, d\alpha.$$

Therefore, at any angle, $Ld\omega$ becomes

$$2\,\pi\, i_p \cos \alpha \sin \alpha\; d\,\alpha.$$

For the sphere the total radiation is

[1] Strutt, The light scattered by gases; its polarization and intensity. Proc. Roy. Soc. A95: 155. 1919.

$$2\,\pi\, i_p \int_{\alpha=0}^{\alpha=\frac{\pi}{2}} \cos\alpha \,\sin\alpha \, d\,\alpha = \pi\, i_p \left| \sin^2\alpha \right|_0^{\frac{\pi}{2}} = \pi\, i_p.$$

This is 0.6 times the incident light. Therefore i_p, the vertical radiation per unit solid angle, is 0.6 or 0.2 of the normal incident radiation, and therefore $p = 0.2$.

In the paper by Fowle the fractional transmission of dry air above Mt. Wilson, altitude 1730 meters, is given. As on page 73,

$$I_a = I_t \, exp \left(\frac{cd_o}{b} \left(e^{-bt} - e^{-ba} \right) \right).$$

Here $a = 173{,}000$ cms; t is very great, since we have the transmission of the whole layer, and hence $I_a : I_t$, which is the fraction given by Fowle, is

$$e^{\frac{-cd_o}{b} \cdot e^{-ba}}.$$

We know b, a, and d_o, which are, respectively, 123, 108, 173,000 and 0.001293 in c. g. s. units. Therefore, we can find c for any wave-length for which the fraction is tabulated. The expression on page 73, then, gives h for any altitude a. In the following table, f is an average value of the fractional transmission of air above Mt. Wilson, and h is the haze effect, as defined, at an altitude of 10,000 ft. The wave-length is given in Å. U.

λ	f	h
3500	.630	0.086
3710	.686	0.067
3970	.752	0.050
4130	.783	0.042
4310	.808	0.036
4520	.840	0.029
4750	.863	0.024
5030	.885	0.019
5350	.898	0.017
5750	.905	0.016

In the table below values of h at various altitudes are given for $\lambda = 4000$ Å. U. These values are represented graphically on page 78. It will be seen, by comparison with field data, that the haze effect at $\lambda = 4000$ Å. U. due to dry air, is about one-fifth that found.

a (ft.)	h	a (ft.)	h
1,000	0.0051	6,000	0.0298
2,000	0.0103	7,000	0.0344
3,000	0.0151	8,000	0.0390
4,000	0.0204	9,000	0.0436
5,000	0.0248	10,000	0.0480

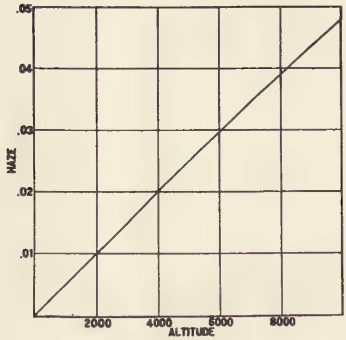

Fig. 38

It may be remarked in closing that the haze altitude curve for dry air, though very nearly a straight line, is a little convex upward. (Fig. 38.) If we should plot h for a homogeneous medium, by aid of the formula on page 76, for the case of $b = 0$, the curve would be concave upward. The effect of a decrease of density of the haze material with altitude appears to be to straighten this curve, or even to change its curvature until it becomes convex upward, as is the case for air. The magnitude of these effects, however, depends upon the relative values of the constants (d_o, b, c) involved.

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